Training Resources for Solar Water Pump Testing

Part 2

February 2023

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Introduction

Since 2019, VeraSol has been developing technical resources related to SWP testing in partnership with Schatz Energy Research Center. These resources include:

- Global LEAP Solar Water Pump Test Method , which describes laboratory testing procedures for measuring and evaluating energy performance, quality, and durability evaluation; as well as
- SWP Durability Research Memo, which identifies the common durability issues observed from the testing process and recommendations for how to enhance pump durability.

To further expand the technical resources for SWPs, the VeraSol team has developed a series of training documents for testing facilities and technicians interested in learning more about SWP testing. The documents include standard operating procedures (SOPs) for performing tests based on the Global LEAP test method.

Version	Date	Summary
1.0	8/30/22	Initial drafting of this SOP.

Scope / Field of Application

This procedure will include the Reverse Polarity test, the Dry Run test, and the Full Tank test. Reverse Polarity and Dry Run are classified as protections tests, meaning that they evaluate whether a solar water pump has proper protection against installation or use errors. Full Tank test is included in this procedure because the process is very similar to the Dry Run test; however, it is not classified as a protection test.

The Reserve Polarity test assesses the pump's ability to avoid damage when non-permanent electrical connections are wired in reverse polarity.

The Dry Run test assesses whether a pump has proper protection against low water levels or a dry well.

The Full Tank test assess whether a pump has the capability to stop pumping water once the storage tank is full.

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customized by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

SOP – Standard operating procedure

SWP – Solar water pump

Responsibilities

SWP tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks, if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test results, and provides input as needed. Also, may communicate directly with the client, as needed.

Materials Required

- *SWP test bench*
- *Stopwatch*
- *Cup of water (for dry run and full tank)*

Pre-Test Preparation

Do not perform the Reverse Polarity or Dry Run test until after the performance tests have been finished as these tests are potentially destructive. If the mechanical durability tests will be done with the same sample, it is best practice to perform these tests prior to mechanical durability.

Before this test is carried out, the following SOPs must have been read and followed:

- *1 SWP Testing Safety*
- *2 SWP Intake and Visual Screening*
- *3 SWP Testing Set up*
- Steps 1-31 in the *6 SWP Solar Day* SOP must have been carried out to calculate the required simulated irradiance steps and ensure the Chroma and LabView have been set up correctly for the SWP under test.
- *7 SWP Protections Test and Full Tank* SOP (this SOP must be reviewed prior to testing, and especially if this procedure has been updated since the last time the tester has tested)

Ensure all safety trainings have been provided to operate the test bench.

Procedure

Reverse Polarity

This test only has to be done if it is possible to reverse or incorrectly wire any non-permanent connections.

1. Determine which of the following scenarios are relevant for the pump and follow the instructions under each one (you may have to perform several scenarios):
    a. SWP does not have an external, separate controller and has non-permanent, reversible PV connectors (i.e. bare wires or screw terminals)
        i. Turn the power off (switch the Chroma output off in the software so that no power is on the PV leads while configuring this). It is best practice to have the Chroma unit physically turned OFF as well to be extra sure no power will enter the PV leads while wiring.
        ii. Swap the PV positive and PV negative leads on the pump.
        iii. Proceed to step 3.
    b. SWP includes an external, separate charge controller or inverter that is connected between the PV and the pump.
        i. Turn the power off (switch the Chroma output off in the software so that no power is on the PV leads).
        ii. Swap the PV positive and PV negative in the external controller (see Figure 1)
        iii. Proceed to step 3.

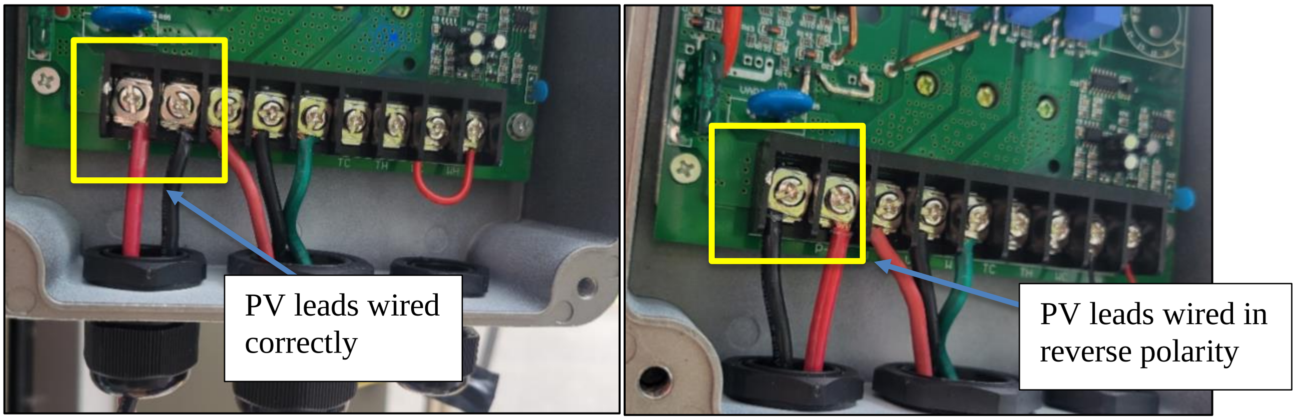


Figure 1: Example of reverse polarity on PV leads within an external controller.

c. SWP has an external, separate controller that has non-permanent connections between the controller and the pump.
   i. Turn the power off (switch the Chroma output off in the software so that no power is on the PV leads).
   ii. Mismatch the leads coming from the pump to the controller within the controller screw terminals or connectors. In most cases, there will be more than two wires connecting the controller to the pump, so it is the SWP testers discretion to choose which of the wires to switch.
   iii. Proceed to step 3.

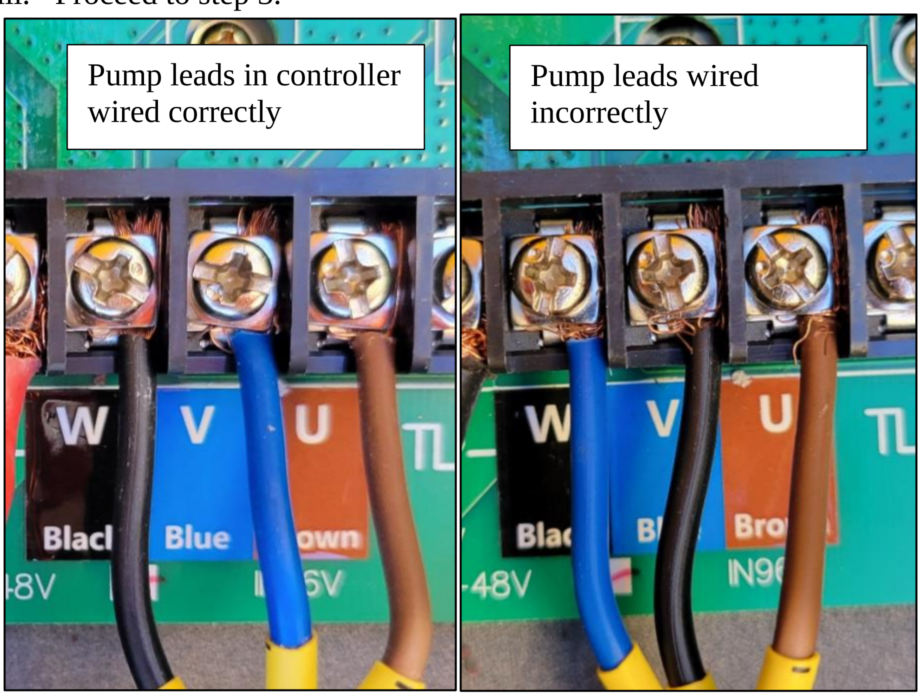


Figure 2: Example of mismatched controller to pump leads.

2. If there are any other non-permanent connections that can be reversed, be sure to consult the Lab Manager to determine if the scenario is necessary to test.
3. Once the reverse polarity is wired, simulate a PV power equivalent to 700 W/m^2 on the

Chroma software for 20 minutes (as long as no safety hazards are observed). The high ball valve may be fully opened so as to not add more pressure to the system.

4. Document and note any damages or hazards. Be sure to take pictures of the reverse polarity configuration for the report.
5. Re-wire the pump, controller, or PV back to its correct configuration and note whether the pump is functional to its original performance, and if there were any damage or safety hazards observed.
6. Repeat steps 3-5 with all the possible scenarios.

Dry Run Test

1. Determine the most likely dry-run protection mechanism:
    a. If the pump came with an external water-level sensor and instructions to connect it, then connect the sensor as described.
        i. Common external water-level sensors tested have been different types of float switches, and one example of this type of sensor is shown in Figure 3 below.
    b. If the pump did not include an external sensor and there is no clear way to connect a generic sensor, then assume the pump has built-in water level protection that can be achieved by removing the intake hose or pump from water.
    c. If the pump does not come with a sensor, but there is a way to connect a generic sensor or advertisements that generic water level sensors can be used, then use a generic sensor if one is available to the lab.

Figure 3: Example of a generic water level sensor (this one is a float switch device).

2. With the pump connected to the test bench in the same configuration used for the performance tests:
    a. ensure the high flow ball valve is fully open to simulate as close to zero meters of head as possible
    b. ensure the water level sensor is submerged (if applicable)
3. Simulate a PV power equivalent to 700 W/m^2 using the Chroma software.
4. Let the pump stabilize for five minutes such that the flow is not fluctuating by more than 5%.
5. After the five-minute waiting period, get a stopwatch ready and simulate a dry-well scenario by:

   a. Removing the water level sensor from water or;
   b. If the pump is assumed to have built-in dry run protection, remove the pump from the water or remove the intake hose from the water.
6. Immediately start the stopwatch and stop it once the pump has come to a complete stop.
7. Note this time directly into the reporting spreadsheet (shown in Figure 6).
8. Let the test run for two minutes and if the pump does not shut off, then the pump is determined to not have dry run protection.
   a. Note if two minutes does not seem safe to the testers, it is within tester's discretion to cease testing before two minutes of dry run has passed.
9. Either place the sensor, pump, or intake hose back into the water after and observe whether the pump is functional.
10. Note and document any damage sustained during testing in the reporting spreadsheet for the SWP under test (see reporting section below).

Full Tank Test

The Full Tank Test is only required for pumps that advertise the ability for the pump to stop pumping water once the storage tank is full.

1. Set the pump up with the advertised Full Tank mechanism (typically the same or very similar water level sensor that is used for Dry Run protection). Note that this may be wired differently to the external controller, if applicable.
2. With the pump connected to the test bench in the same configuration used for the performance tests:
   a. ensure the high flow ball valve is fully open to simulate as close to zero meters of head as possible
   b. ensure the water level sensor is completely out of the water.
3. Simulate a PV power equivalent to 700 W/m^2 using the Chroma software.
4. Let the pump stabilize for five minutes such that the flow is not fluctuating by more than 5%.
5. After the five-minute waiting period, get a stopwatch ready and simulate a full tank scenario by submerging the sensor into water or using whatever full tank mechanism is described in the advertisements or consumer facing material.
6. Immediately start the stopwatch and stop it once the pump has come to a complete stop.
7. Note this time directly into the reporting spreadsheet (shown in Figure 4).
8. Let the test run for two minutes and if the pump does not shut off, then the pump is determined to not have Full Tank capabilities.

Reporting

There are three distinct sections in the "Test Results" tab of the reporting spreadsheet that are for the two protections tests (Reverse Polarity and Dry Run) and the Full Tank test.

1. The Full Tank test has a results section titled "Full Tank Test" which is directly below the first section labelled "General Testing Information". The pieces of information needed to fill in this section are:
   a. Sample used – typically Sample 1
   b. Simulated Irradiance – 700 W/m^2
   c. Evaluation of protection – yes or no

d. Time taken for the pump to turn off – time in seconds

Full Tank Test

Sample	Simulated irradiance [W/m²]	Protection?	Time taken for pump to turn off [s]
1	700	yes	10

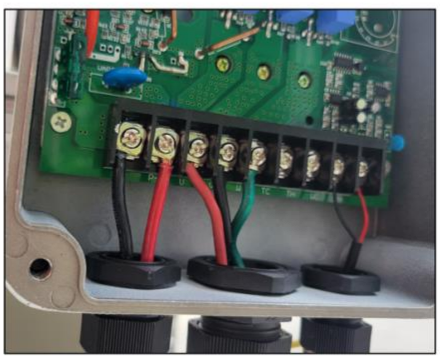
Comments:	The provided sensor was wired into the "TC" and "TH" screw terminals within the controller. Once the sensor was placed into the water, the "Tank" indicator on the controller lit red and the pump turned off in about 10 seconds.

Photo: Water level sensor for the water storage

Figure 4: Full-tank test results filled out.

2. Both the Dry Run Test and Reverse Polarity are in a section labeled "Protection Tests". The Reverse Polarity section is the first under the "Protections Tests". In this section, fill out the types of reverse polarity tested for the pump and note the following:
   a. Is the pump functional with the polarity reversed?
   b. Was there damage?
   c. Any safety hazards?
   d. Is the pump functional after returning to normal polarity?
3. The Reverse Polarity Test also requires pictures of the reverse polarity configuration.

Protection tests					
Reverse Polarity					
Sample	Description of reverse polarity	Functional when polarity is reversed?	Damage?	Safety Hazards?	Pump functional after test and when normal polarity is used?
1	PV leads reversed	no	no	no	yes
1	Pump leads reversed	yes	no	no	yes
Comments:	When the PV leads were reversed, the pump was not functional, and the controller did not turn on or show any error indication. When the pump leads were reversed, the pump was functional but produced a much lower flow around 40 lpm. There was no damage when the leads were placed back in the correct position, and the pump functioned normally.				
Photo- Cable plugs and ports wired in reverse polarity					



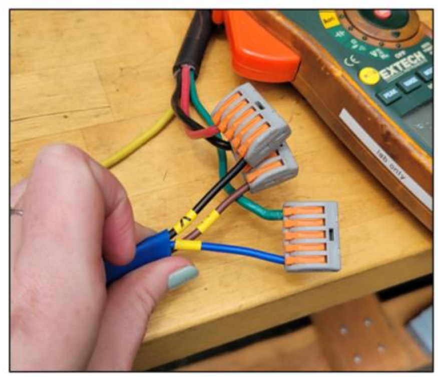


Figure 5: Example of the Reverse Polarity section filled out.

4. The section immediately following Reverse Polarity is the Dry Run Test section which is identical to the Full Tank Test section. Fill in the same information described in step 1.

Dry run protection test

Sample	Simulated irradiance [W/m^2]	Protection?	Time taken for pump to turn off [s]
1	700	yes	9

Comments:	The provided sensor was wired into the "WC" and "WH" screw terminals within the controller. Once the sensor was removed from the water, the "Well" indicator on the controller lit red and the pump turned off in about 9 seconds.

Water level sensor for the water source

Figure 6: Dry Run Protection Test section filled out.

5. After filling out the relevant sections in the "Test Results" tab in the reporting spreadsheet, be sure to hide unneeded rows and remove the colors from the background of the cells.

Version	Date	Summary
1.0	8/30/22	Initial drafting of this SOP.

Scope / Field of Application

This procedure encompasses the three mechanical durability tests: Switches, connectors, and/ or goosenecks; Cable Strain Relief; and Drop Test. These tests are meant to evaluate how a pump withstands general wear and tear as well as general robustness and durability.

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customized by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

SWP – Solar water pump

SOP – Standard operating procedure

Responsibilities

SWP tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks, if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test results, and provides input as needed. Also, may communicate directly with the client, as needed.

Materials Required

- *SWP Test Bench*
- *Strain Relief apparatus (including custom wooden angle supports)*
- *Stopwatch*
- *Camera (to capture failures or damage)*
- *Meter stick*

Pre-Test Preparation

Ensure that all required performance and protection tests are completed prior to this procedure as the Mechanical Durability tests could potentially destroy the pump and leave it inoperable. If two samples were received for testing, then perform the Mechanical Durability procedures on sample 2 (the sample that **did not** undergo the performance testing). The tests should be performed in order of potential destructiveness (i.e. Switches, connectors, and/ or goosenecks; Cable Strain Relief; then Drop Test.

Before this test is carried out, the following SOPs must be read and procedures carried out (if applicable) for the pump under test:

- *SWP Test Bench Instruction Manual*
- *1 SWP Testing Safety* SOP
- *2 SWP Intake and Visual Screening* SOP
- *3 SWP Testing Set up* SOP
- *4 SWP Cold Start and Inrush* SOP
- *5 SWP Head Range* SOP
- *6 SWP Solar Day Test* SOP
- *7 SWP Protections Test and Full Tank* SOP
- *8 SWP Durability Tests* SOP (this SOP must be reviewed prior to testing, and especially if this procedure has been updated since the last time the tester has tested)

Ensure all safety trainings have been provided to operate the test bench.

Procedure

Switches, connectors, and/ or goosenecks

This test examines the durability of the product's moving parts. Switches are turned on and off 1000 times; connectors are connected and disconnected 1000 times for each port (i.e. USB, power supply connector, PV module connector- note this is not required for MC4 connections as these types of connectors are meant to be more semi-permanent and not expected to be connected and disconnected with the same kind of frequency), and goosenecks and other moving parts are bent/moved 1000 times through their feasible range of motion.

1. Identify which switches, connectors, and goosenecks will need to tested. If the SWP has multiple identical switches or connectors, only one of the set of identical connectors must be tested. Some examples are shown below of switches that would need to be cycled 1000 times:

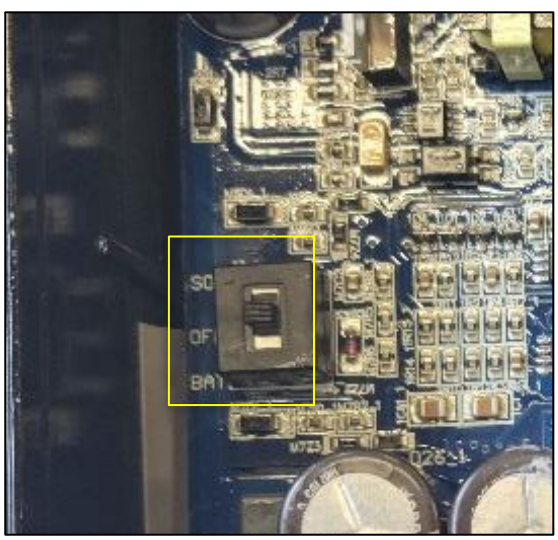


Figure 1: Switch inside of the controller that is subject to the switch test.

Figure 2: On/Off switch on the outside of controller that is subjected to the switch test.

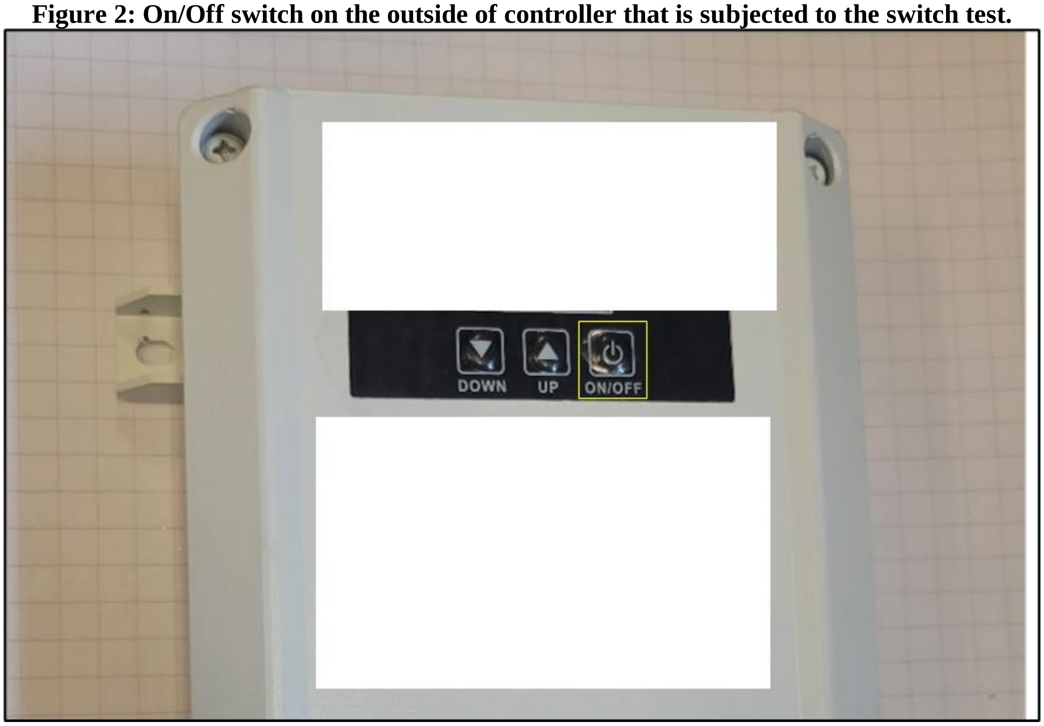


Figure 3: ON/OFF button that will need to undergo the switch test.

2. If you are unsure whether something needs to be tested, consult the Lab Manager.
3. Confirm that switches, connectors, or goosenecks are functional prior to the 1000 cycles. It is acceptable to do this by powering the SWP when it's set up to the test bench in the right configuration, and testing the functionality of the switch, connector, or gooseneck.
4. Press the off button in the Chroma Software so that no power is being delivered to the SWP.
5. Operate the first switch, connector, gooseneck, or other moving part through 1000 full cycles while checking for functionality every 100 cycles:
    a. To test for functionality, turn on the Chroma output in the software to simulate a power equivalent to 700 W/m^2 as determined in the Solar Day Test.
    b. Observe if the pump functions normally and produces flow (be sure to check that the flow produced after cycling is similar to the flow produced prior to the cycling).
    c. Test out the switch, connector, or gooseneck at this time to ensure it still functions.

d. Also observe if there are any user safety issues posed during testing, and consult the Lab Manager if it seems unsafe to continue the other cycles.
e. If functional, continue to the next 100 cycles. If not, note how many cycles were achieved, and photograph any visible damage.

6. Repeat steps 3-5 for all switches, connectors, or goosenecks.
7. See the reporting section below for how to enter results into the reporting spreadsheet.

Cable Strain Relief

The strain relief test measures the mechanical integrity of the cords on SWPs, PV modules, and other accessories. The strain relief test simulates the natural pulls and forces the sample's cords may experience. For the simulation, the cord is subjected to a 2 kg weight for 60 seconds at various strain angles (i.e. 0º, 45º, 90º).

Only cables that are permanently attached on at least one of the cable ends are tested using this procedure; this test method does not apply to connectors or non-plug-and-play connections (i.e. screw terminals or clamps).

1. Determine which cables will need to undergo strain relief. Typically, the pump cable and PV cable (if PV is included) will undergo strain relief.
2. Verify functionality prior to strain relief testing. For a pump, turn the pump ON in the same configuration used during performance testing. For a PV module, cut the electrical cable close to its plug and measure the open-circuit voltage and short-circuit current with the module facing the sun using a digital multimeter. Write these values down for reference after this test has been completed.
3. Confirm that the clamp and weight have a combined mass of 2.000 kg, using either a calibrated scale or a reference calibrated weight to make the confirmation.
4. Start with the 0° angle for the cable as this is the least destructive angle. Place the SWP in a vice grip to hold it in place and use a level to confirm that the SWP is at 0° (so that the cable hangs directly below the pump vertically).

Figure 4: SWP cable in the vice grip for the 0° configuration.

5. Clamp on the pre-weighed 2 kg weight onto the cable in the proper configuration and start the stopwatch as soon as the weight is released from the testers hand. Let the weight hang freely for 60 seconds, then remove the weight from the cable.
6. Test the component for functionality.

a. For testing the SWP cable, hook the component onto the test bench following the Testing Set Up procedure (*1 SWP Testing Set Up SOP*) and test for functionality by powering the pump at 700W/m2 and comparing its performance to how it performed prior to starting the strain relief test
b. For testing a PV cable, measure the Voc and Isc with a digital multimeter like how it was done in the step prior to starting this test, and compare the Voc and Isc to the original measured values.

7. Note and photograph any damages or safety hazards.
8. If the component is functional and there are no damages, remove the component from the test bench (if applicable), and set it up for the 45° angle.
9. The 45° can be achieved using the strain relief apparatus (custom wooden angle supports) shown in Figure 5. Due to the weight of most SWPs, this is most easily achieved using the vice grip for pump cables.

Figure 5: Pump cable set up in the strain relief apparatus for 45° angle testing.

10. Once the component is set-up for the 45° angle, repeat steps 5-7.
11. If the components are functional and there are no damages, remove the component from the test bench (if applicable) and set it up for the 90° angle.
12. The 90° angle can also be achieved using the vice grip if needed (ensure the cable is hanging perpendicular to the component). Once set-up for 90°, repeat steps 5-7.

Figure 6: Pump set up for 90° angle.

13. Repeat steps 4-10 for each cable that must undergo strain relief.
14. Record and note damages or angles achieved prior to failure.

Drop Test

Only test portable, surface pumps or portable appliances/accessories if advertised as portable (which may include submersible pumps in most cases). Always perform drop test last as it is the most potentially destruction durability test. It is the tester's discretion not to test a SWP if they think it may pose a safety risk.

1. Determine if the pump needs to be dropped by evaluating if the pump is portable (i.e. portable surface pump or submersible pump advertised to be portable).
2. Verify functionality of the pump prior to testing.
3. Identify and label (using a permanent marker or sticker) all sides of the device: 1, 2, 3, 4, 5, 6
4. Hold the pump one meter above a solid, hard surface with the side labeled "1" facing toward the ground as shown in Figure 7.

Figure 7: Pump held at one meter above the ground using a meter stick.

5. Release the pump from the one-meter position to impact on a hard, flat surface.
6. Photograph the pump and note and damages or hazards.
    a. If the pump comes loose or separates in a way that can be easily put back together, then the drop test can continue at the tester's discretion.
    b. If there are clear damages to the products casing that presents sharp edges, exposed electrical leads, potential shorting, or other hazards to the user or product, photograph and do test for functionality if unsafe. Consult a Lab Manager if unsure.
7. If there are no safety hazards or damages, test the pump for functionality and repeat steps 4-6 on the next side until you've tested all six sides.
8. After the Drop Test is complete, the sample that was dropped should undergo a separate internal inspection in parallel with the general internal inspection. Follow the Internal Inspection SOP (*9 SWP Internal Inspection SOP*) for guidance on how to open the pump. Note any internal damages that resulted from the mechanical durability tests.
    a. If the same sample was used for performance testing and drop test, just follow the typical internal inspection.

Reporting

All three mechanical durability tests are in a section of the *Test Results* tab in the reporting spreadsheet labeled "Mechanical Durability".

1. In the Switches, connectors, and/or goosenecks section enter:
    a. Description of the switch, connector, or gooseneck that was tested.
    b. Number of cycles achieved.

c. Was the component functional?
d. Was there damage?
e. Were there safety hazards?
f. Any relevant photos of damage or hazards.

Switches, connectors, and/or goosenecks test						
Sample	**Description of switch, connector, or gooseneck tested** *(ie Pump "ON" button, Controller "ON" button, etc.)*	**Number of cycles completed**	**Functional?**	**Damages?**	**Safety Hazards?**	**Results**
1	On/Off switch	1000	yes	no	no	PASS
Comments:	One cycle for the on/off switch was from the on position to the off position and back.					

Figure 8: Switches, connectors, and/or goosenecks section filled out in the reporting spreadsheet.

2. In the Cable Strain Relief section, enter:
    a. Angles tested
    b. Functionality
    c. Damages
    d. Safety hazards
    e. Any relevant photos of damage or hazards.

Cable strain relief						
Tested Cable:	Pump cable					
Sample	**Angle Tested**	**Time with 2 kg weight hanging on cable [seconds]**	**Functional?**	**Damages?**	**Safety Hazards?**	**Results**
1	0°	60	yes	no	no	PASS
1	45°	60	yes	no	no	PASS
1	90°	60	yes	no	no	PASS
Comments:						

Figure 9: Cable Strain Relief section filled out in the reporting spreadsheet.

3. For both *Switches connectors, and/or goosenecks* and *Cable strain relief*, the results section will fill in with "FAIL" is any of the following are true:
    a. The "Functional?" section is filled in with "No"
    b. The "Damages" section is filled in with "Yes"
    c. The "Safety Hazards" section is filled in with "Yes"
4. In the Drop Test section, enter:
    a. Description of each numbered side
    b. External and internal damage
    c. Functionality

d. Damages
e. Safety hazards
f. Photos of each side of the pump that was dropped and any resulting damage.

Drop test

Tested Unit:	Pump in frame

Sample	**Description of side that was dropped** *(side facing the ground when dropped)*	**External inspection--damage observed?**	**External inspection--safety hazards observed?**	**Results of External inspection**
1	The bottom of the frame was faced toward the ground; the handle was faced up (side marked "1").	no	no	PASS
1	Long-side of the frame marked "2" was face-down.	no	no	PASS
1	Long-side of the frame marked "3" was face-down.	no	no	PASS
1	Short-side of the frame marked "4" was face-down.	no	no	PASS
1	Short-side of the frame marked "5" was face-down.	no	no	PASS

Was tested unit tested for functionality after drop test?	yes

Sample	**Description of side that was dropped** *(side facing the ground when dropped)*	**Functional?**	**Damages?**	**Safety Hazards?**	**Overall results**
1	The bottom of the frame was faced toward the ground; the handle was faced up (side marked "1").	yes	no	no	PASS
1	Long-side of the frame marked "2" was face-down.	yes	no	no	PASS
1	Long-side of the frame marked "3" was face-down.	yes	no	no	PASS
1	Short-side of the frame marked "4" was face-down.	yes	no	no	PASS
1	Short-side of the frame marked "5" was face-down.	yes	no	no	PASS

Figure 10: Drop Test section filled out in the reporting spreadsheet.

5. For both *Drop Test*, the results section will fill in with "FAIL" is any of the following are true:
   a. The "External Inspection—damage observed?" section is filled in with "Yes"
   b. The "External inspection – safety hazards observed?" section is filled in with "Yes"
6. Once the mechanical durability sections are filled out, remove the background color from the cells and hide any unneeded sections.

Reference Procedures

This procedure references IEC/TS 62257-9-5:2018 Annex W

Version	Date	Summary
1.0	8/30/22	Initial drafting of this SOP.

Scope / Field of Application

This procedure aims to thoroughly examine the internal components of solar water pumps to properly document, report, and describe the components and any signs of damage or hazard.

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customized by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

SWP – Solar water pump

SOP – standard operating procedure

Pump – a device that moves fluid

Pump type – a designation for the pumping mechanism (i.e. centrifugal, helical rotor, positive displacement, etc.)

Impeller – the fan-shaped rotating part of a centrifugal pump

Motor – a device that converts electrical work into mechanical work

Bearing – a low friction device that allows for easy rotation

Rotor – rotating part of the motor (can be wire coils or a magnet)

Stator – stationary part of the motor (can be wire coils or a magnet)

DC – direct current

AC – alternating current

Submersible – water pump that is designed to be fully submerged in water during use, typically in a well or borehole

Surface – water pump that is designed to sit outside of the water source and pull water from one location to another

PPE – personal protective equipment

Responsibilities

SWP tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks, if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test results, and provides input as needed. Also, may communicate directly with the client, as needed.

Materials Required

- *Screwdriver*
- *Wrench (various sizes or adjustable)*
- *Pipe wrench*
- *Bench Vise*
- *Pliers*
- *Oil disposal/storage*
- *Spill tray*
- *Shop towels*
- *Camera*
- *Jar or other small, clear container*
- *Safety glasses/ (maybe) face shield*
- *Disposable gloves*
- *Ear plugs*
- *Clean, clear container to examine oil*

Pre-Test Preparation

Before this test is carried out, the following SOPs must be read and procedures carried out (if applicable) for the pump under test:

- *SWP Test Bench Instruction Manual*
- *1 SWP Testing Safety*
- *2 SWP Intake and Visual Screening*
- All performance and durability test SOPs (internal inspection will destroy the pump and leave it inoperable)
- *9 SWP Internal Inspection*

If two samples were received for testing then perform the internal inspection procedure on sample 1 (the same sample that underwent the performance testing). Sample 2 will undergo the mechanical durability tests and a separate internal inspection, if applicable, which is described in the Mechanical Durability SOP (*8 SWP Durability Tests*).

Many SWPs will have a large amount of oil within them; ensure to have a recycling disposal plan in place, and follow local environmental regulations and recommendations.

Safety Precautions

- Always wear proper PPE when performing the internal inspection; this should include closed-toed shoes, safety glasses, gloves, and clothing that adequately covers your skin. Ear plugs or earmuffs may be required if loud power tools or saws are required during this procedure for a given SWP.
- Pumps can be heavy and should be handled with caution to prevent injury from improper lifting or dropping.
- Pumps may contain hazardous or toxic fluids that should be handled with precaution.

- **NEVER use heat to disassembly a pump** as this can cause an explosion due to flammable internal fluids.
- Be aware of sharp metal edges, and always have a first aid kit close by. Heavy cloth gloves can be used if there are sharp edges; however, be aware that they may need to be thrown away if a large amount of oil gets onto the cloth.
- Always know where the closest fire extinguisher is and how to use one (if you need a training, discuss with the Lab Manager to plan this).
  If you need to use a tool you are unfamiliar with in order to perform this procedure, consult with the Lab Manager so a path forward may be mapped out.

Procedure

1. Ensure that all steps in the preceding section, “Pre-Test Preparation,” have been completed.
2. Every solar water pump will be different and may have a unique process to access the internal components. This procedure will guide through some typical cases and the key components to identify.
3. Begin by gathering all equipment and laying the pump on a spill tray. Most pumps will have a large amount of oil within the motor enclosure that will need proper disposal and will also need to be contained to prevent contamination.
4. Ensure that the camera you are using is close by, and make sure to document as much as possible throughout the internal inspection.

Every solar water pump will be different and may have a unique process to access the internal components. There are two main categories of pumps: submersible or surface. Submersible pumps are meant to be fully submerged in water during operation, while surface pumps are designed to sit outside of the water source. The diagram below shows the typical way that the two pump types may be designed and can help identify larger sections and the language used to describe them:

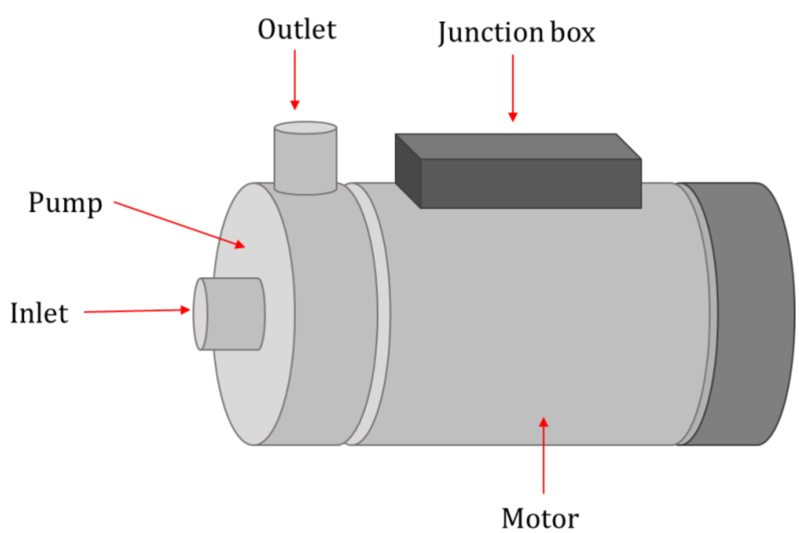


Figure 1: Typical layout of a surface solar water pump.

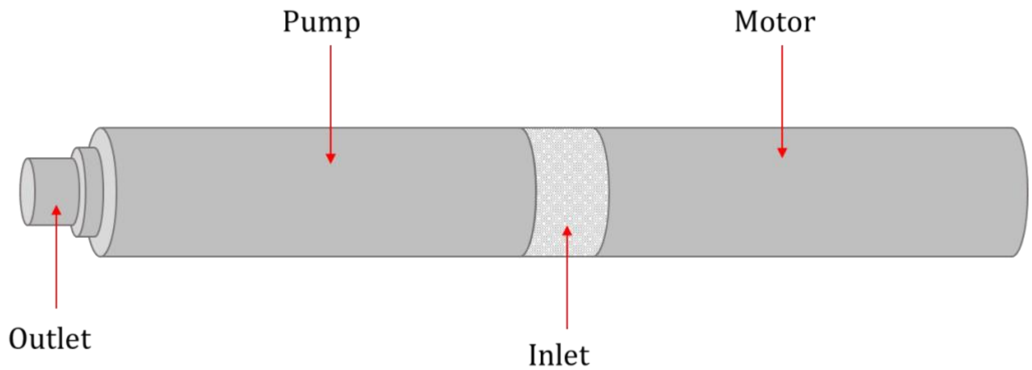


Figure 2: Typical layout of a submersible solar water pump.

This procedure will guide through some key components to identify and some typical cases as well as many examples.

Disassembling the pump

Most submersible and surface pumps are very similar to others in their respective categories in the way that they are constructed. The main difference between pumps will likely be the pump mechanism (i.e. centrifugal, helical rotor, etc.). The process for disassembling submersible and surface pumps will be different, so an example for each case will be shown throughout the procedure. It should also be noted that there are differences between pumps even within the same pump category. Therefore, it is important to note that a great deal of problem-solving and troubleshooting will be required if a pump is not a generic surface or submersible pump. If there is any confusion or uncertainty on how to open a specific pump, **consult a Lab Manager before using any power tools or unconventional methods as injury could occur if proper precaution is not taken.**

1. Begin the internal inspection by removing all visible external screws and all easily removable external pieces such as the cable case and screen:

Figure 3: External screws on a submersible water pump.

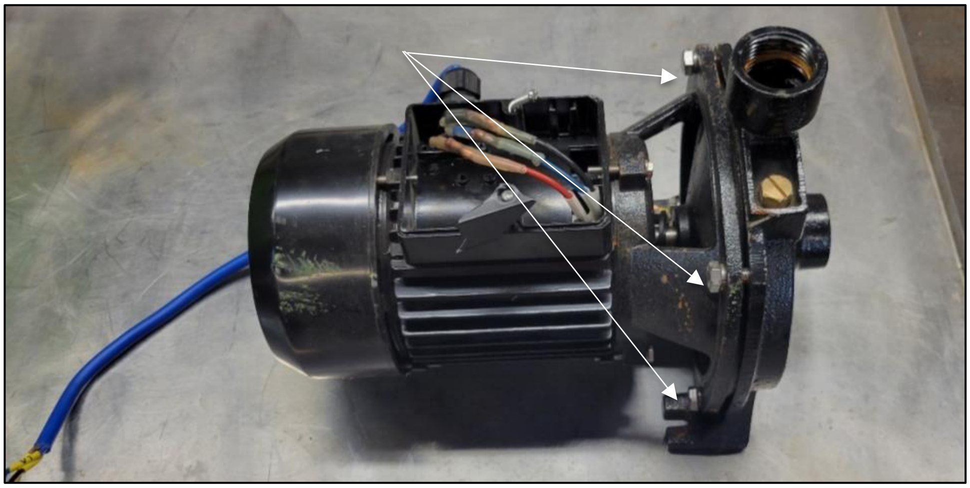


Figure 4: External screws on a surface pump.

2. Separate the pump end from the motor end.
    a. For submersible pumps there is usually a set of bolts or screws that connect the pump-end to the motor-end in the middle section of the body. Figure 5 below shows two different pumps and the different bolt types used. One uses an Allen wrench bolt, and the other uses a hex bolt.
    b. For surface pumps, there may not be a clear way to separate the pump body from the motor because there are likely not two distinct parts like a submersible pump. In this case, start removing the covers near the inlet and outlet to begin exposing the pumping mechanism.
        i. Many surface pumps will not have an oil-filled motor enclosure like submersible pumps. If it is expected that the surface pump will be filled with oil, identify the entry point to the motor enclosure and skip to step 4.
        ii. If there is no oil within the motor enclosure of the surface pump, skip to step 6.

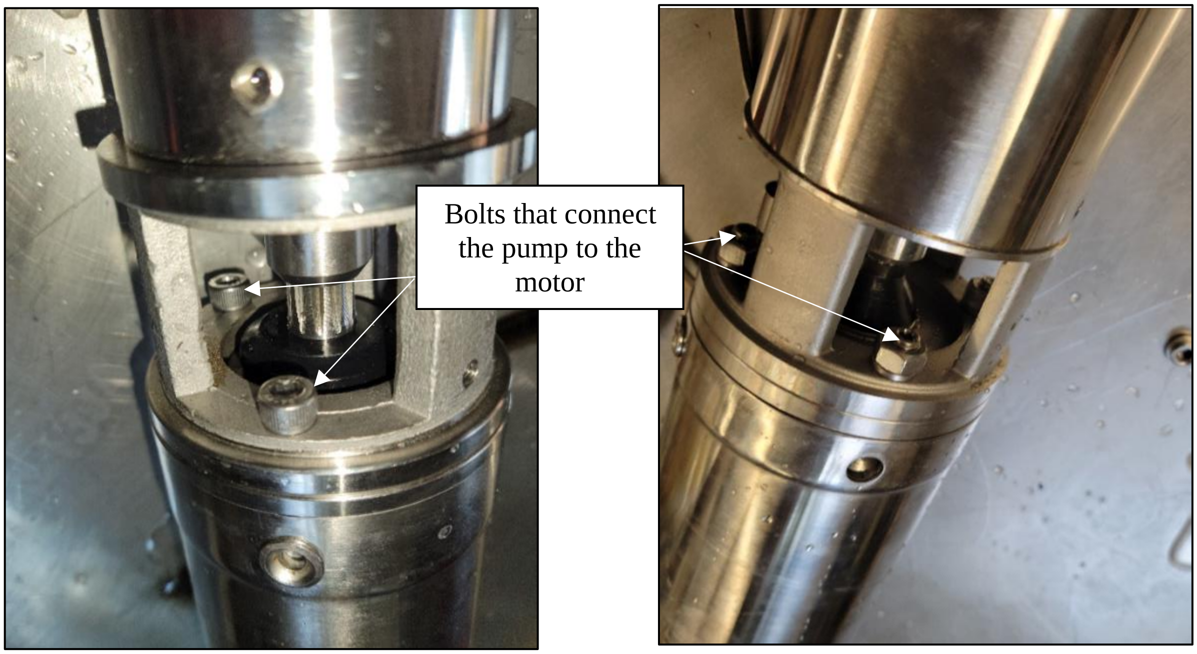


Figure 5: Example of how the pump and motor sections are typically connected on a submersible water pump.

3. For submersible pumps, after removing the bolts in the center section, the pump and motor sections can be separated from one another (in most cases). This can be useful as the motor section will contain the oil that needs to be drained. There are typically two places to drain the oil, either from the pump-end of the motor enclosure or from the base of the motor enclosure:
    a. The pump-end may have a specific screw in place that allows for the oil to be drained, see Figure 6 below.

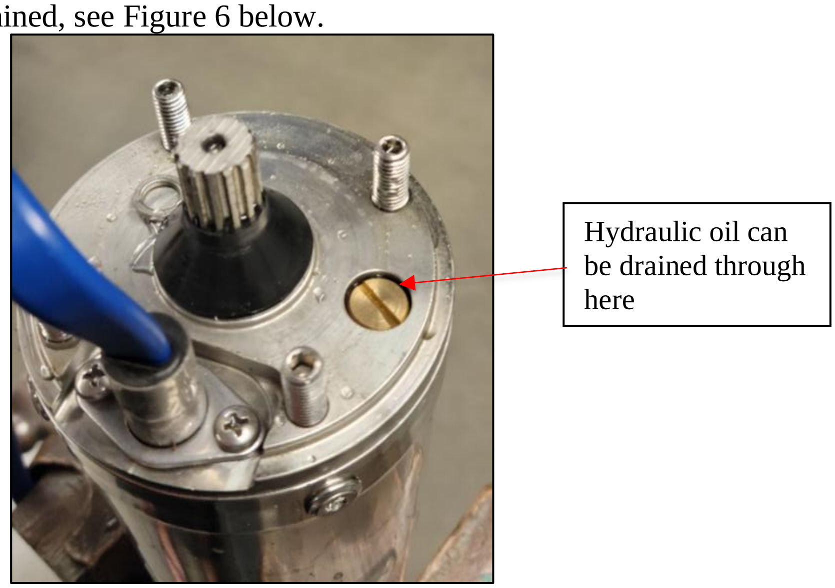


Figure 6: Oil drain on the top of the motor (pump-end of the motor).

    b. Another way to drain the oil is on the base of the motor enclosure. There is often a ring hose clamp, rubber seal, or other mechanism meant to seal the motor oil. By removing this seal, the oil can be drained from the base of the pump.

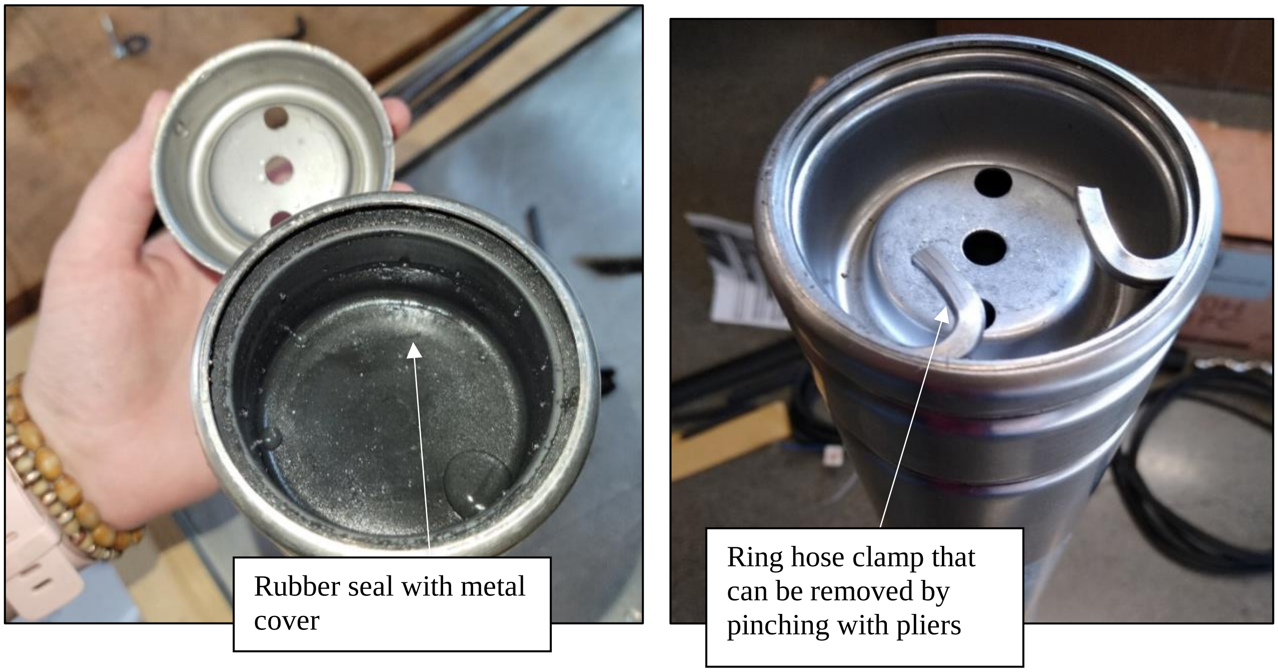


Figure 7: Motor enclosure seal on the base of the motor

4. Begin carefully draining the oil into a clear, clean container for documentation (see Figure 8). The clean, clear container does not have to fit all of the oil from the motor but should be large enough to see the color, quality, and clarity of the oil. Be sure to take pictures of the oil that was drained from the motor, and note if any of the following are present:
    a. Color and clarity: is the oil relatively clear and see-through?
    b. Quality: is the oil free of debris and particulate?
    c. Signs of water: is there any water in the oil or any signs that water may have entered from the pump into the motor enclosure?
    d. Rust: is there a grainy orange color or rust debris in the oil?

Figure 8: Example of submersible pump motor enclosure being drained into a container for observation.

Figure 9: Example of clear and good quality oil (left). Example of debris and rust in motor oil (right).

5. After draining and documenting the oil from the motor enclosure, use shop towels to clean any spills and properly dispose of the oil (following local and/or national recommendations specific to the location of the lab).
6. The next step is to begin disassembling the motor enclosure.
    a. For submersible pumps, this process can look quite different for each pump. Typically, the pump-end cap of the motor can be removed by pushing it out by force. There are also some cases where the pump-end cap should be twisted off. The only way to determine which case is by trial and error.
    b. In the example below (Figure 10, Figure 11, and Figure **12**), there were some Allen key screws on the pump-end of the motor and some screws on the side that need to be removed. Then, the gold-colored end can be pushed out.

i. *Typically, a screwdriver or other strong rod-shaped object can be placed in the hole of the side screw and tapped with a hammer to begin pushing the gold cap off the end of the motor.*

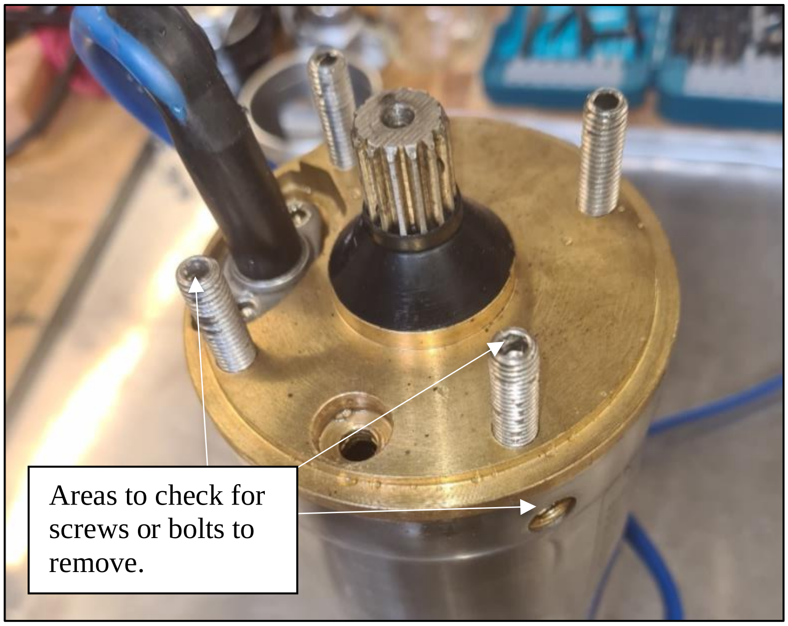


Figure 10: Screws and bolts that hold the end cap onto the motor

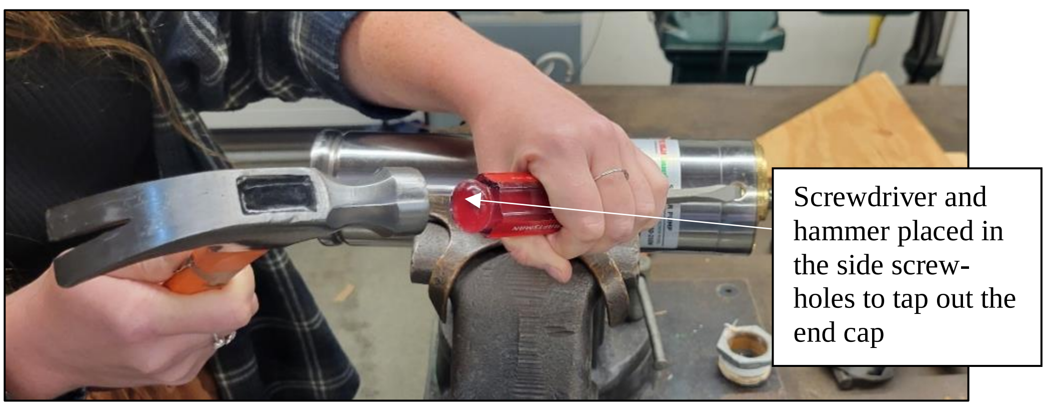


Figure 11: Technique to nudge the end cap out of the motor enclosure.

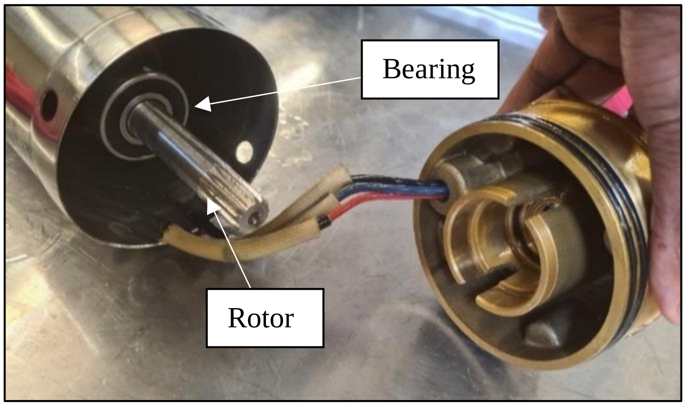


Figure 12**: Pump with the end cap removed exposed the rotor and bearings.**

c. For surface pumps, there may not be one universal way to gain access to the pump motor and more trial and error may be necessary. Typically, the motor can be accessed after the pump section has been opened and disassembled. Then, once the pump end is removed, the bearing and rotor can be accessed. To skip to the pump disassembly, go to step 9.

7. Once the motor is opened, the rotor will likely be able to be removed from the motor entirely. The rotor is either a collection of coiled wires (either brushed or brushless DC) or a large magnet (induction AC motor). In either case, the rotor should be able to be removed by nudging it out from the stator using a little force (either pushing from the back of the motor or pulling from the pump-end of the motor. The goal of removing the rotor is to examine the following components:
    a. Rotor- document the rotor and note the type (two examples below).

Figure 13: Two different rotor types are shown: one belongs to a brushless DC motor (left) and the other belongs to an induction (AC) motor.

b. Stator- document the stator and note the type (two examples below).

Figure 14: Two different stator types: one that is a part of an induction (AC) motor (left) and another that is a part of a DC motor (right).

c. Bearing(s)- this is a key component to document in the internal inspection because the bearings are typically a point of deterioration. The brand, model number, and quantity of bearings will be documented in the report as well as the type, the seal, and the material of the seal.
   i. The model number and brand- this is typically printed on the bearing itself and many pumps will have two or more bearings with different brands and/or model numbers

Figure 15: Example of close-up pictures documenting the brand and model number printed on the bearing.

   ii. Bearing type- the majority will be deep groove ball bearings. If the type is unknown, try searching the model number and brand name to figure it out.
   iii. Bearing seal- the bearings will either be sealed or unsealed and if they are sealed, the seal can be various materials. The presence of a seal is usually determined by whether the steel balls within the bearing are visible. Figure 15 shows two examples of sealed bearings, one sealed with stainless steel (left) and one sealed with rubber (right).

Figure 16: Example of an unsealed bearing.

8. After disassembling the motor, be sure to note and document any damage or hazards including:
    a. Any signs of water within the motor enclosure* (especially around the bearings as these getting wet can lead to significant deterioration).
    b. Signs of significant rust or deterioration.
    c. Poor wiring quality or poor soldering quality.
    d. Sings of corrosion.
    e. Any other concerns including excessively sharp edges, user safety risks, physical damages that could impede functionality, etc.

**There are some cases of water-cooled motors, which are designed to allow water into the motor, but these cases are uncommon.*

Figure 17: Example of signs of rust within the motor enclosure which is also a sign of unwanted water entering the motor enclosure.

Figure 18: Example of poor wiring quality (no solder, poor crimping, not insulated, etc.)

Figure 19: Example of signs of corrosion within the motor enclosure.

9. Next, the pump-side should be disassembled and documented.
    a. For surface pumps, the pump-side can usually be accessed by removing the external bolts near the inlet and pulling off the end-cap.

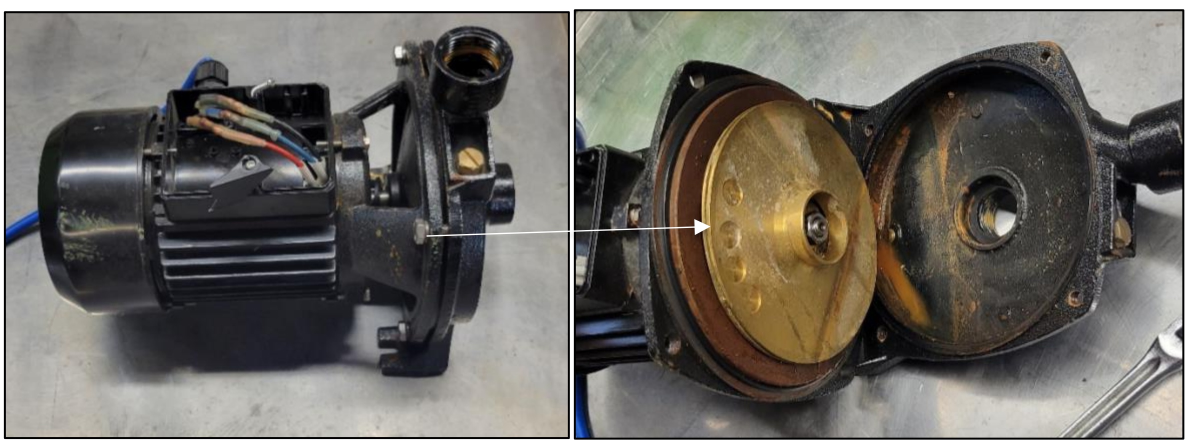


Figure 20: Surface pump enclosure removed to expose the impeller.

    b. For submersible pumps, typically one of the pump-ends has to be removed.
        i. Typically, both the motor-end of the pump (pump cap that is closest to the motor) and the top of the pump (typically where the outlet is located) can be removed by twisting. This usually requires quite a bit of force, so it is recommended to use a pipe wrench and a vice grip to hold the pump in place.

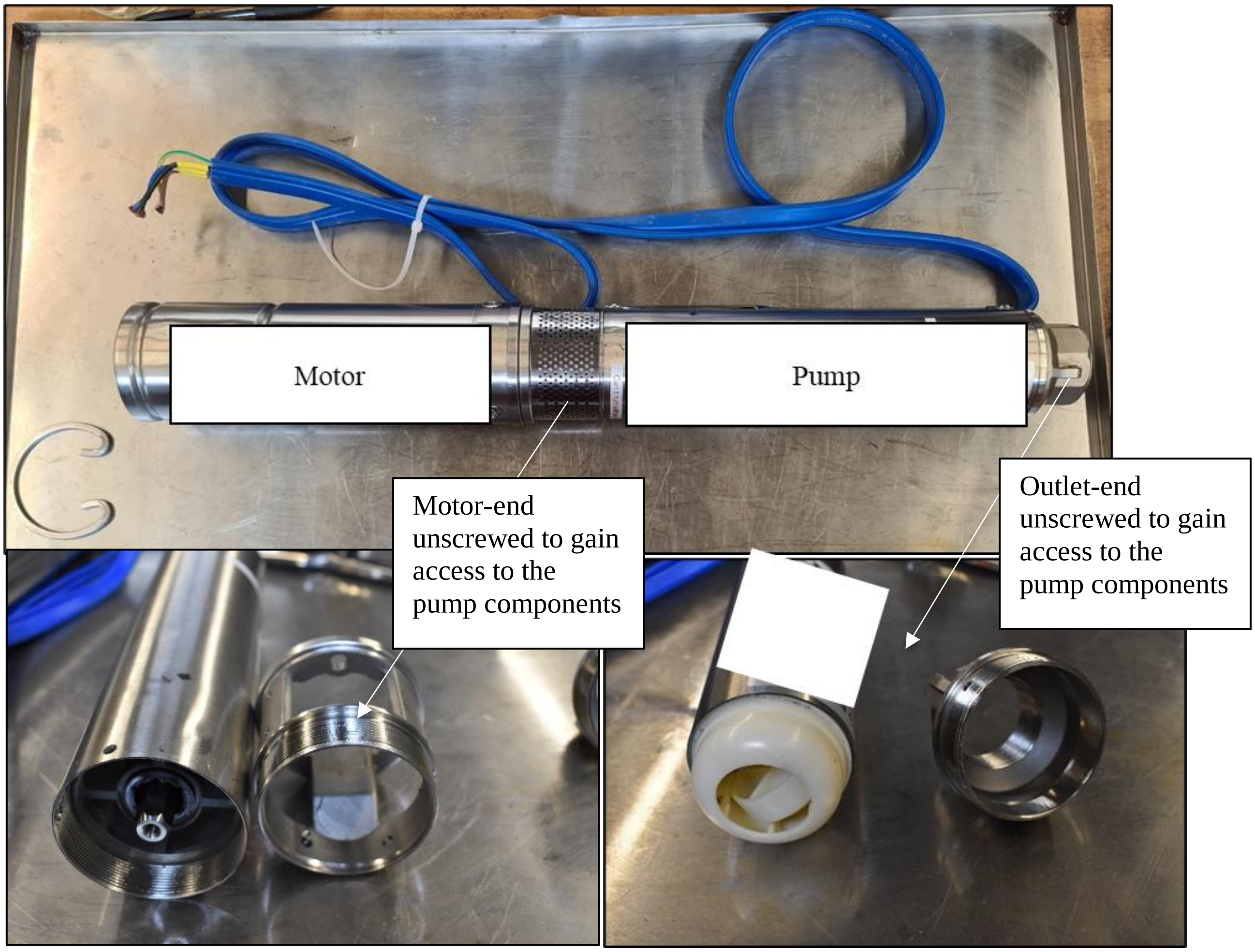


Figure 21: Two ways to access the pump section of a submersible pump.

10. Once the pump section has been opened, the pumping mechanism can either be removed or documented within the pump case. The main thing to document is the pumping mechanism, and if the pump is centrifugal, the impeller type.
    a. The pump type for both surface and submersible pumps will one of three: centrifugal, helical rotor, or positive displacement. Centrifugal and helical rotors are the most common. See examples below:

Figure 22: Example of submersible centrifugal pump.

Figure 23: Example of a submersible helical rotor pump.

Figure 24: Example of a surface helical rotor.

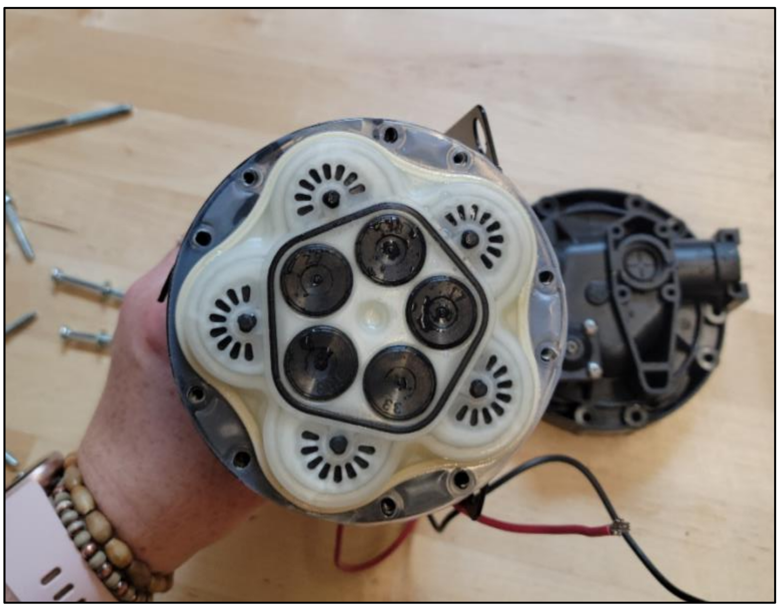


Figure 25: Example of a surface positive displacement pump.

b. The impeller type should be documented for centrifugal pumps. There are three types of impellers: open, closed, and semi-closed, refer to Figure 26.

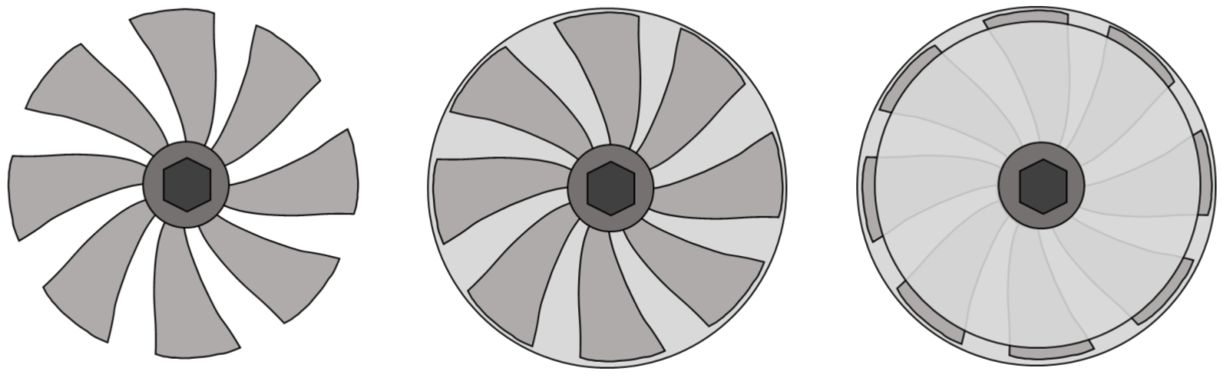


Figure 26: Diagram showing the three impeller types.

11. After disassembling the pump section, be sure to note any damages including:
    a. Signs of rust
    b. Physical damages
    c. Improper or poor wiring
    d. Other safety and functionality issues.
12. The internal inspection is now complete, if there are any unique components or unusual mechanisms, be sure to thoroughly photograph them for the report.

Reporting

The internal inspection portion of the report is located in the *Visual Screening* tab of the *SWP Reporting Template* spreadsheet.

1. Fill in the "Indicators" section with a description of any indicators on the pump body (i.e. power on LED, error LED, etc.)
2. The next section is the "Internal Components" section, where the information regarding bearings and impellers should be filled in.
3. The next section is "Functionality and Workmanship", which requires the tester to answer various questions regarding how the pump functions and the quality of the internal components. If there are any noteworthy sections, leave a comment to describe the answer that was chosen.
4. An example of the section filled out is shown below:

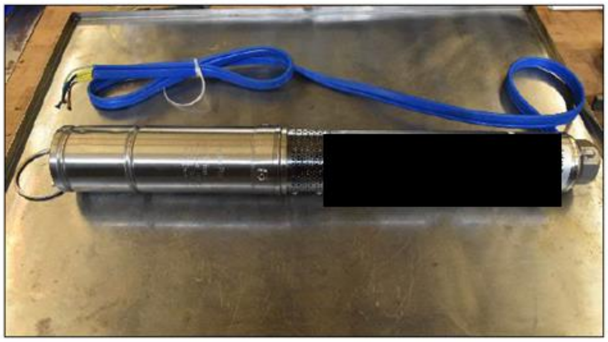
Pump internal inspection / functionality test

Category	Parameter (name of indicator)	Description	
Indicators	--	N/A, there are no indicators on the pump	
Internal Components	Type of impeller (open, closed, semi-closed):	[redacted]	
	Bearing brand/model, if known:	[redacted]	
	Type of bearing unit, if known:	[redacted]	
	Number of bearing units:	[redacted]	
	Are the bearings sealed?	[redacted]	
	Material of seals	[redacted]	
Category	Parameter	[yes/no]	Comments
Functionality	Do all switches/buttons function?	N/A	No switches present on pump.
	Do all ports function?	Yes	MC4 ports on controller are functional, there are no ports on the pump body.
	Do all indicators function?	N/A	No indicators present on pump.
Workmanship	Are there any poor solder joints?	No	--
	Are there any wiring deficiencies?	No	--
	Are all internal components properly secured?	Yes	All wires are neatly connected and secured within the pump; all other components fit securely within the enclosure.
	Are there any safety concerns?	No	--
	Are there any sign of water inside of enclosure?	No	--
	Does the pump have a water-cooled enclosure design? *(i.e., is water intended to enter the enclosure)*	No	--
	Are there any moving parts (such as the impellers, rotor, bearings, etc.) or sensitive electronics exposed to water within the enclosure?	No	--
	Is there any rust or corrosion observed within enclosure?	No	--
	Is there oil inside of the pump that will need to be disposed of?	Yes	The oil inside of the motor enclosure is clear and clean.

Figure 27: Example spreadsheet filled out after internal inspection.

5. The next section the "internal pictures of the pump" and is two consecutive blank spaces for the tester to add pictures and small descriptions of the image. An example of this section is shown below:

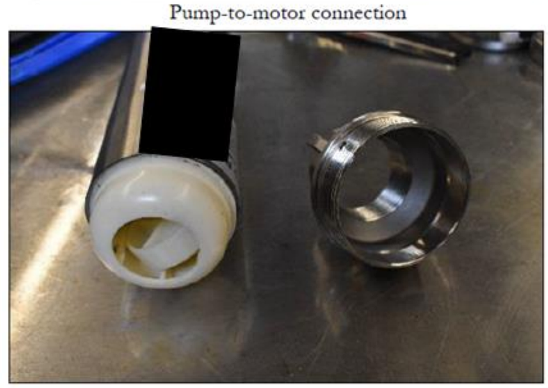
Internal picture(s) of pump



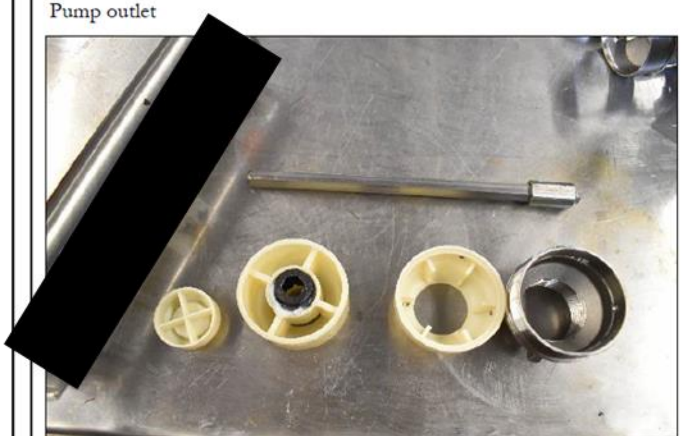
Overall pump and motor body

Pump-to-motor connection

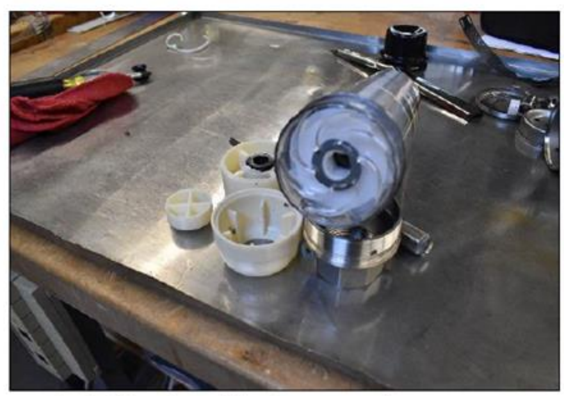
Pump outlet



Pump outlet with metal cap removed



Impeller cover



Stacked impellers within the pump casing

Figure 28: Photos from internal inspection filled into the report.

6. The last section for the internal inspection is the "Overall Safety Evaluation"; This is where the tester should rate the pump and describe why the rating was given using the following definitions:

a. **Good** – No deficiencies were observed, and none of the moving parts or sensitive electronics of the pump are exposed to undesired water within the enclosure.
b. **Satisfactory** – One or two small/ insignificant workmanship deficiencies were observed such as missing screws or small deformities that do not affect overall functionality or safety.
c. **Needs improvement** – Many small workmanship deficiencies were observed such as multiple missing screws or deformities that do not affect the functionality of the product. Or small amounts of rust were observed that may affect the long-term functionality of the product. Some of the moving parts in the pump are exposed to undesired water that affects the performance of the pump but does not make the pump fail to function.
d. **Poor** – Many or significant issues such as large amounts of rust or loose wires were observed that affected the overall functionality of the product or pose safety concerns. One or more of the moving parts in the pump and/ or sensitive electronics have been exposed to undesired water and have significant rust and/ or effect on the pump's function or consumer safety.
    i. The ratings are tester discretion, but the main separator between "needs improvement" and "poor" are long term versus immediate safety and functionality issues, respectively.
    ii. See examples in Figure 29 below.

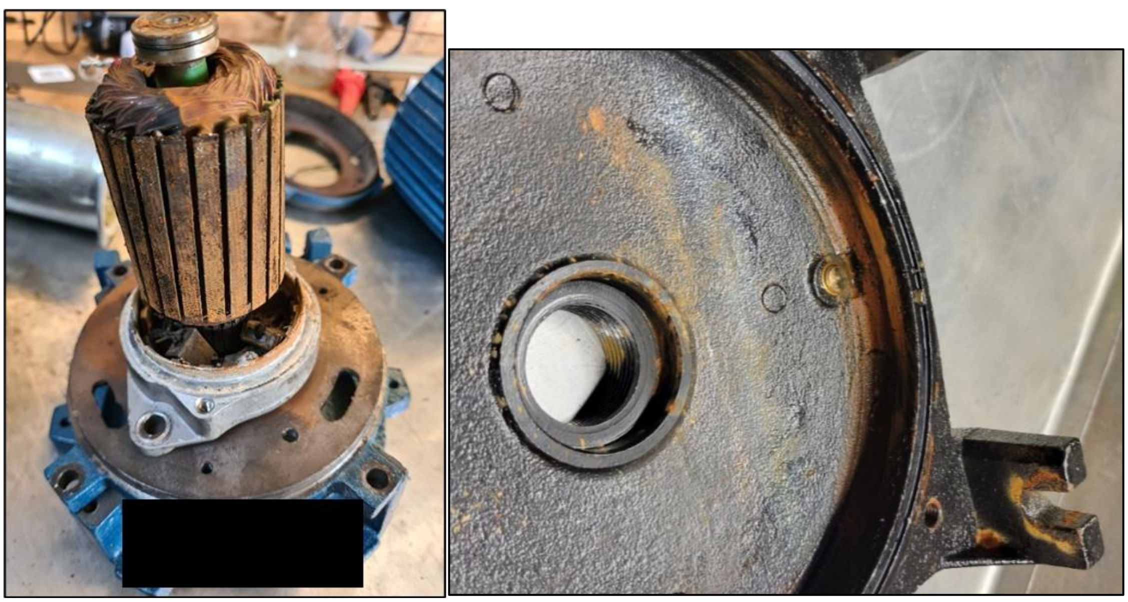


Figure 29: Example of a pump which received a "Poor" rating due to large quantities of rust and corrosion within the motor enclosure which will likely cause significant damage in the short term (left). Example of a pump which received "Needs improvement" due to small quantities of rust outside of the motor enclosure which will likely cause longer term issues.

7. Be sure to remove the coloring from the cells and expand rows so that none of the comments or text is cut off.

Version	Date	Summary
1.0	8/26/22	-first version of this document

Scope / Field of Application

This document specifies procedures for calibration, in-house calibration (characterization), checks, and maintenance of laboratory equipment used for solar water pump (SWP) testing. The schedules for performing these tasks is defined in the calibration schedule tabs of the *SWP_EquipmentRecords* spreadsheet.

Note that currently, third-party accredited calibrations are only required upon purchase of new measurement equipment, if there is known damage of equipment, or on measurement devices used for in-house calibrations for SWP testing. The intervals and guidelines for this equipment are recommendations; however, it is hopeful that this testing work remains frequent, and the test methods can be updated to include a required calibration interval for each measurement unit used for testing in the future.

The following types of procedures are specified in this document:

Third-party calibrations- Instruments that cannot be calibrated in-house are sent to a third-party ISO 17025 accredited calibration laboratory, if possible. This document does not include instructions for how to send items out for calibration; rather it describes where this information can be found and suggestions based upon manufacturers recommendations and research. Note that not all equipment will be outlined in this document. Also note that this type of calibration is only required:

1. upon first time purchase of equipment,
2. or if there is known damage to equipment where repair and recalibration is needed,
3. or on measurement equipment used specifically as reference devices for in-house calibrations.

In-house calibrations- In-house calibrations are performed on equipment using measurement devices that have an accredited calibration. These calibrations include the DAQ voltage and current measurements and the DAQ pressure offset. These are items that can be adequately calibrated using third-party calibrated equipment on-hand, such as the Fluke 287 digital multimeter (DMM).

Check- properly checking equipment is essential to producing quality test results. This manual includes procedures for checking lab equipment, and general guidelines for the frequency of these checks. For the full equipment check schedule, see the most recent revision of the *SWP_EquipmentRecords* spreadsheet.

Maintenance- properly maintaining equipment is also essential to producing quality test results. This manual includes procedures for maintenance activities, and general guidelines for the frequency of maintenance. For the full maintenance schedule, see the most recent revision of the *SWP_EquipmentRecords* spreadsheet.

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customized by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

SWP- solar water pump

DAQ- data acquisition

DMM- digital multimeter

Responsibilities

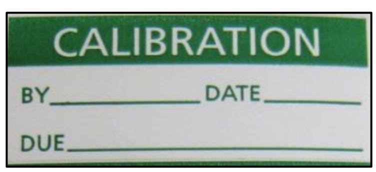
SWP tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks, if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test results, and provides input as needed. Also, may communicate directly with the client, as needed.

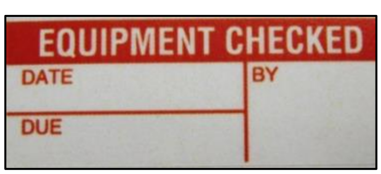
Equipment labeling

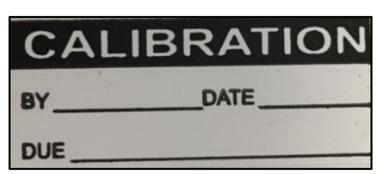
All laboratory equipment that is listed in the *SWP_EquipmentRecords* spreadsheet should be labeled, such as with the stickers shown below. The areas on the label that are filled out include the person who performed the procedure, the date it was performed, and the date that the next procedure is due.

The **calibration** label is used for equipment calibrated by an accredited third-party laboratory. This sticker should be used even if the third-party calibration laboratory affixes its own sticker. This indicates that the equipment has been checked to ensure that it is functioning properly after being shipped from the calibration laboratory and that the equipment meets our requirements, which are outlined below in the third-party calibration procedure.



Measuring equipment that is characterized in-house against reference devices or standards, such as a multimeter with accredited calibration, is labeled with an equipment checked label or black calibration label. These labels are used for lab equipment that has been characterized and for equipment that has undergone regular maintenance activities.





Measuring equipment that has failed calibration or is deemed out of service should be labeled with an **out of service** sticker. This equipment should not be used until it the problem has been corrected.

Materials Required

Each procedure outlined below will list the materials required to perform each.

Pre-Test Preparation

Ensure all safety trainings have been provided to operate the test bench, and that the *1 SWP Testing Safety SOP* and the *SWP Test Bench Instruction Manual* have been read.

Procedure- Third-Party Calibrations

As stated, third-party calibrations currently are not required in most circumstances for the SWP testing equipment at this time. This section will describe only recommendations should the test lab want to pursue sending out equipment and setting requirements for equipment calibrations.

Reference the *SWP_EquipmentRecords* spreadsheet to know when each item listed is due for calibration. There are several tabs in this spreadsheet, and the *Third-Party* tab should be referenced for the items listed in Table 1, below. The figure below shows the layout of this tab of the spreadsheet, which is essentially a table that lists the proposed schedule for each unit, checks that should occur when a unit is third-party calibrated, and additional notes.

Note that because these types of calibrations are not currently required and all calibrations performed outdates this SOP and equipment schedule, the actual calibration dates for several equipment will be unknown but will be filled-in once a schedule is established.

Month	Third Party Calibration	Current status	Notes	Serial #	Recommended Interval (months)	Check that vendor is approved	Intake- scan calibration report and save on computer; save hardcopy in SWP Equipment file	Intake- test for functionality	Intake- update calibration sticker, date in this spreadsheet	Suggested calibration vendor	2019 Completed	2019 Next due	2022 Completed	2022 Next due
Jan	Pressure transducer Omega PX409-250GV	Overdue	Request quote here: https://www.omega.com/en-us/calibration-flow-page		48	x	x	x	x	Omega	1/1/19	1/1/22		
Feb	Flowmeter with signal conditioner - Omega FTB 103	OK	Request quote here: https://www.omega.com/en-us/calibration-flow-page		12	x	x	x	x	Omega	2/1/19	2/1/24		
Mar	Flowmeter with signal conditioner - Omega FTB 107	OK	Request quote here: https://www.omega.com/en-us/calibration-flow-page		12	x	x	x	x	Omega	3/1/19	3/1/24		
Apr	Chroma 62150H-600S	OK	email service@chromausa.com		12	x	x	x	x	Chroma USA	4/1/19	4/1/24		
May	DC Current transducer- CR5220-70	OK	https://www.transcat.com/quote-request		12	x	x	x	x	Transcat	5/1/19	5/1/24		
Jun	Stopwatch	OK	https://www.transcat.com/quote-request		12	x	x	x	x	Transcat	6/1/19	6/1/24		
Jul	2Kg weight	OK	https://www.transcat.com/quote-request		12	x	x	x	x	Transcat	7/1/19	7/1/24		
Aug	Clamp meter Extech EX830	OK	https://www.transcat.com/quote-request		24	x	x	x	x	Transcat	8/1/19	8/1/24		
Sept	WattNode Module for Modbus- WND-M1-MB, Opt BAUD=19200, AD=1	OK	https://www.transcat.com/quote-request		48	x	x	x	x	Transcat	9/1/19	9/1/24		
Oct	PULS Power supply- CS10.241; AC 100-120' 200-240V; DC 24-28V, 10A	OK	https://www.transcat.com/quote-request		as needed	x	x	x	x	Transcat	10/1/19	10/1/24		
Nov	meter stick	OK	https://www.transcat.com/quote-request		as needed	x	x	x	x	Transcat	11/1/19	11/1/24		
Dec	Fluke 287	OK	https://www.transcat.com/quote-request		as needed	x	x	x	x	Transcat	12/1/20	12/1/24		

Figure 1. *Third-Party* tab from the *SWP_EquipmentRecords* spreadsheet to track the schedule of calibrations.

There are several columns in the table within the *Third-Party* tab. Starting from the left, the following is an explanation of each columns in this table:

- *Month*: this should be filled in with whatever month the equipment will be sent out to a third-party each time it is ready for re-calibration. In a frequent testing environment, it may make the most sense to set a schedule for each unit where items are sent out in different months so that some testing can still move forward while some of the equipment are being calibrated. It is up to the lab to decide what works best for their testing schedule.

- *Name of equipment*: this column lists the equipment name and model number, if applicable.
- *Current status*: this column will automatically turn red and say "overdue" or remain green and say "OK" depending on whether or not today's date is past the "next due" calibration entry (last column in the spreadsheet) to inform the tester that the unit should be sent out. Note that it also will automatically turn yellow and say "Next 30 days" if a calibration due date is approaching in the next month from today's date.
- *Notes*: this is a column to write any helpful notes about how to request for a calibration, website/ manufacturer information, etc.
- *Serial number*: fill out the serial number, if applicable, for each unit.
- *Recommended interval (months):* this is the recommended recalibration interval deemed by the lab, which may be based upon manufacturer recommendation, current use of the equipment for testing, what type of calibration the lab wants to pursue, and additional research. This column may be updated, if needed; however, it usually remains unchanged.
- The next four columns are to help the tester perform checks when sending or receiving back equipment to/ from a third-party calibration lab. The "x" in each of these columns should be deleted after each interval for each piece of equipment so that the next time the item is sent out, the "x's" can be filled back in as the tester runs through the following checks/ procedures:
    - *Check that vendor is approved:* this approval will be determined on what type of calibration the lab wants to require for each piece of equipment and what set of conditions the lab sets for choosing a vendor for calibration. For instance, should the lab decide these calibrations be required, it should be determined what requirements to set for their calibration lab vendor for each equipment. Some ideas are listed below:
        - Reputation of lab/ company
        - Manufacturer of the equipment/ recommended by the manufacturer
        - Accreditation certificate on-hand
        - Contact information available/ personnel are responsive
    - *Intake- scan calibration report:* all calibration reports with uncertainty data should be scanned and saved electronically along with saving a hardcopy to ensure the record is on-file and to use calibration data perhaps for other in-house procedures.
        - For this, it helps to have a designated folder on the server to save these reports in.
    - *Intake- test for functionality:* once receiving back the equipment and installing it again, if applicable, its functionality should be tested to ensure no damage was inflicted during shipping/ calibration.
    - *Intake- update calibration sticker/ update dates in table:* follow the guidance in the section above for affixing calibration stickers to equipment after calibration is done. Also, fill in the calibration date and next calibration due day (depending on the calibration interval determined for the equipment) in the spreadsheet to the right.

- *Suggested calibration vendor:* this column lists some suggested calibration vendors for each piece of equipment. These vendors might be ones that were researched or recommended by other sources, or they could be vendors the lab has already used in the past. This is just helpful information to have on-hand.
- *The last two columns will be listed under the current year*. Each year, make two more columns to the right with the same sub-headers:
  - *Completed:* this is the date that will be on the equipment's calibration report and is when the most recent calibration was completed. This should match the calibration sticker affixed to the equipment as well.
  - *Next due:* this is the date in which the next recalibration is due, which is determined by the set interval.

The only columns that will regularly be filled out in the table are the checks performed before and after sending/ receiving back equipment and the last two columns with dates.

The table below lists equipment that would require an accredited calibration in the exceptional circumstances listed above. It also lists a suggested recalibration interval, should this schedule be followed (or required in all cases in the future), and a recommended calibration company/ lab for each equipment.

Table 1. Equipment calibrated by third-party labs

Equipment	Recommended recalibration interval (years)	Recommended calibration lab
Flowmeter with signal conditioner - Omega FTB 103	1 year	Omega Request quote here.
Flowmeter with signal conditioner - Omega FTB 107	1 year	Omega Request quote here.
Pressure transducer Omega PX409-250GV	4-6 years	Omega Request quote here.
Chroma 62150H-600S- voltage and current output	1 year	Chroma USA Request quote by sending email to Service@chromaUSA.com with M/N, S/N, and state ISO 17025
DC Current transducer-CR5220-70	1 year	Transcat Request quote here.
Stopwatch	1 year	Transcat Request quote here.

2Kg weight	1 year	Transcat Request quote here.
Clamp meter Extech EX830	2 years	Transcat Request quote here.
WattNode Module for Modbus-WND-M1-MB, Opt BAUD=19200, AD=1	4-8 year *4 years if used outdoors/ high humidity	Continental Control Systems, LLC Request for quote here.
PULS Power supply- CS10.241; AC 100-120' 200-240V; DC 24-28V, 10A	As needed	Transcat Request quote here.
Meter stick	As needed	Transcat Request quote here.

Procedure- In-House Calibrations and Maintenance

This section describes procedures that are currently **required** for the test lab for SWP testing equipment. Similar to the third-party calibrations, there is a "In-house" tab in the *SWP_EquipmentRecords* spreadsheet that contains a similar schedule tracker table for all equipment maintained/ calibration in-house.

									fill in each year when a calibration has been completed; add sections as a new year approaches					
									2019		2022		2023	
Month	In-house Calibration	Current status	Notes	Serial #	Recommended Interval (months)	Calibration, Check, or Maintenance?	Testing spreadsheet or software updated with new values from procedure	New calibration stickers and dates updated in this spreadsheet	Completed	Next due	Completed	Next due	Completed	Next due
	Replace ear hose clamps	OK	can check each year; replace as needed	--	as needed	maintenance	x	x	1/1/19	1/1/24				
	Butcher block maintenance	OK	this was update to once a year with our	--	6	maintenance	x	x	1/1/19	1/1/24				
	DAQ voltage and current offsets	OK	this was update to once a year with our	--	12	calibration	x	x	1/1/19	1/1/24				
	Ear clamp crimper	OK		--	12	maintenance	x	x	1/1/19	1/1/24				
	DAQ pressure measurement	OK		--	12	calibration	x	x	1/1/19	1/1/24				
	Test bench vertical head (test bench inlet to pump outlet)	OK	can check each year; when the test bench configuration changes, should do this.	--	12	calibration	x	x	1/1/19	1/1/24				
	Check permanent connections	OK	as needed, check once per year	--	12	check	x	x	1/1/19	1/1/24				
	PVC replacement	OK	check once per year; replace as needed.	--	12	check	x	x	1/1/19	1/1/24				
	angle wood for strain relief	OK	as needed	--	120	calibration	x	x	1/1/19	1/1/24				
	flow meter check	OK	clean out as needed	--	120	check	x	x	1/1/19	1/1/24				
	Wiring check	OK	as needed; check every year	--	12	check	x	x	1/1/19	1/1/24				
	Scale	OK		--	12	calibration	x	x	1/1/19	1/1/24				
	Replace hosing	OK	as needed; check each year	--	12	check	x	x	1/1/19	1/1/24				

Figure 2. In-house calibration schedule.

Refer to the third-party calibration section above to interpret most of this tab/ table since they are very similar. There are, however, less checks the tester needs to record in the spreadsheet for in-house calibrations. The two checks required for in-house procedures include the following:

- Testing spreadsheet or software updated- some of the in-house calibrations determine offsets that need to be applied to test measurement calculations to increase the accuracy of test result data. Some of the procedures listed in this section will provide instructions on where to input the determined equipment measurement offsets in which testing templates used for calculating test results.

- Calibration stickers- this is a check to affix a calibration sticker to each unit after being calibrated.

All required procedures for the equipment in the table listed above are outlined below.

Butcher Block Maintenance

Materials needed:

- *Mineral oil*
- *Dry towel*
- *Stop watch or timer*

Interval:
6 months

Procedure:
The butcher block (table) on the test bench needs to be maintained in order to prevent water damage. Mineral oil must be applied to *all* exposed surfaces of the block every six months if testing is ongoing, and the test bench is being exposed to water frequently over that time. Otherwise, if testing is not ongoing, this procedure shall be done after testing each pump if the test bench is not going to be used in the next, upcoming months. Follow the steps below to carry out this procedure:

1. Ensure the test bench is clean (all debris are wiped off) *and* dry.
2. Apply the first coat of mineral oil by pouring small amounts of the oil on different areas of the table's surface and then using the towel to rub the oil in and disperse it so that all parts of the surface have a coat.
3. Let the oil soak into the wood for at least 30 minutes.
4. Apply the second coat of oil following steps 2 and 3.
5. Wipe off any excess mineral oil.

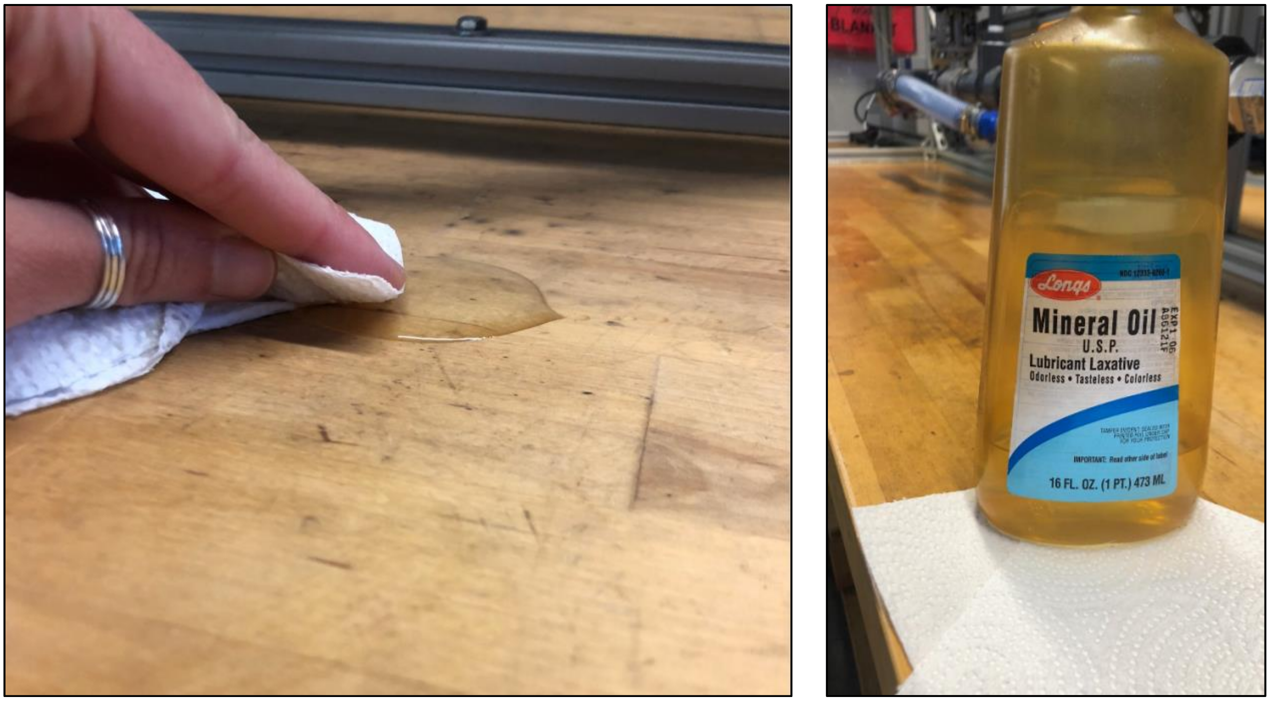


Figure 3. Using mineral oil to apply to butcher block.

Ear Clamp Crimper Maintenance

Materials needed:

- *Machine shop oil*
- *Shop towel*

Interval:

1 year

Procedure:

The ear clamp crimper must be maintained to prevent rust. Machine all-purpose oil may be applied to all connected/ moving parts of the crimper so that the connectors are completely covered (circled in red in the image below).

Figure 4. Crimper and red circles indicating where it should be annually oiled.

Let this sit for 5-10 minutes, and then wipe off all excess oil.

Make sure this crimper is being stored in a cool, dry location. Note that if any rust is noticed, perform this maintenance procedure even if it's off-schedule.

Flowmeter Check

Materials needed:

- *(maybe) small screwdriver*
- *(maybe) pipe wrench*

Interval:
as needed

Procedure:

The flowmeters used for the test bench are very sensitive to dirty water. Their turbines are fragile and can easily get clogged if anything is pumped through the system, including common materials like plant matter and human hair.

If the flow measurements for one or both of the meters seems unexpected or are not functioning at all (LabView might report a negative value for flow or simply "0" while water is flowing, for instance), one or both flow meters should be checked in case debris is clogging it/ them.

To do this, the flow meter must be disconnected from the test bench PVC network; a pipe wrench can help loosen the PVC adapter on either side of the flow meter if needed. The adapters on either side of each flow meter make disconnecting/ connecting these units in-line with the PVC network easier and more possible.

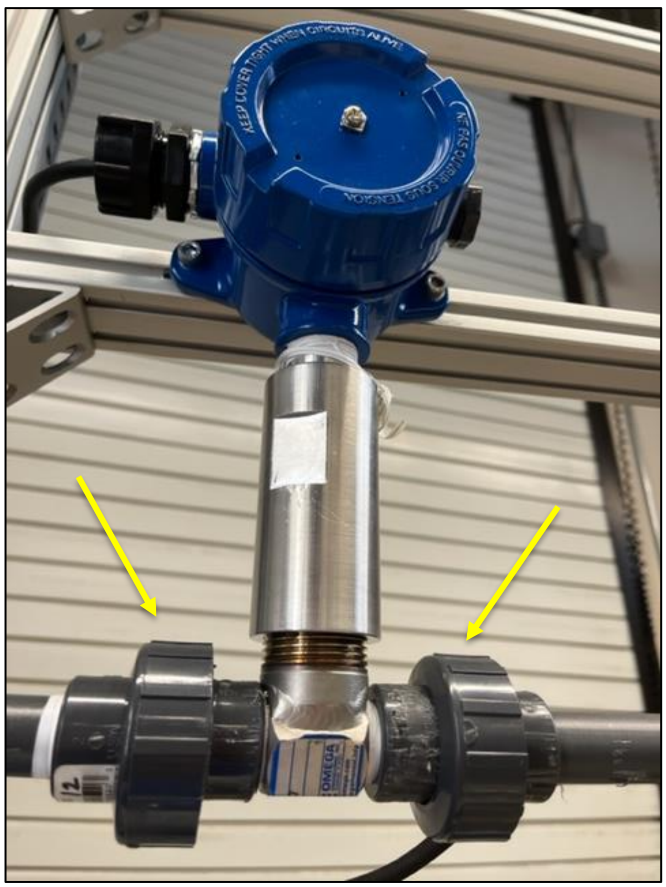


Figure 5. Flow meter and PVC adapters on either side for ease of removing/ re-installing it to the test bench PVC network.

Once disconnected from the PVC network, look inside of the flowmeter's input or output opening on either side so you can see the small turbines within. You may use a small screwdriver to help remove debris from the opening if you notice anything. After removing any debris very carefully, washing through some clean, cool water and blowing some air through the opening can help to ensure there is no more debris within the opening that's trapped.

Check replaceable items

Materials needed:

- *N/A*

Interval:
1 year/ replace as needed

Procedure:
Over years of testing within a pressurized system, some equipment may lose integrity and durability over time. Ensure to check all permanent connection points throughout the test bench each year to assess whether or not each item needs replacement. The most major replaceable items that need to be checked on a regular basis include:

- PVC adapters (yellow arrow in photo below)
- Ear hose clamps (green arrow in photo below)
- Hosing (red arrow in photo below)
- DAQ wiring (blue arrow in photo below)

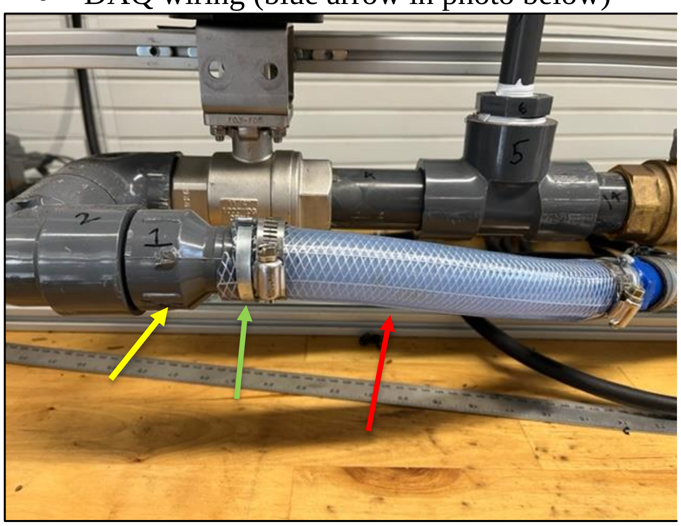


Figure 6. PVC adapter (yellow arrow), ear hose clamps (green arrow), and hosing (red arrow).

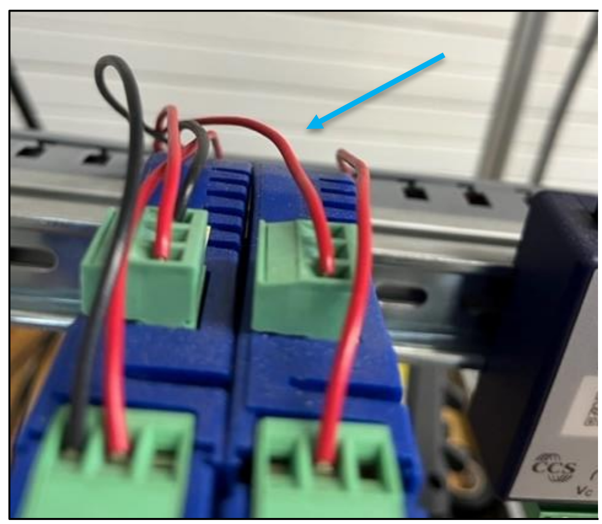


Figure 7. DAQ wiring.

The PVC adapters shall be checked for any cracking, discoloration, or any physical degradation; if this is observed, it may indicate that a replacement should be made. If any PVC adapters are replaced, ensure to properly adhere plumbers' tape when reconnecting; you may follow the guidelines for this outlined in the *SWP Test Bench Instruction Manual*.

If any of the hosing is replaced, also replace the ear hose clamps. Other than that, ear hose clamps should be checked for any rust/ corrosion/ physical degradation; if any of this is observed, then it may indicate that a replacement should be made.

The threaded hosing should be inspected for any discoloration, cracking, tears, stretching, or any other physical degradation; if this is observed, it may indicate that a replacement should be made.

The DAQ wiring should be inspected for any physical degradation including exposure through any portion of insulation, loose permanent connections, any breakages, and more. If any degradation is observed, it may indicate that the wire should be replaced.

Ensure to replace all of these items with materials/ items that are the exact same or better than what was replaced.

Scale

Materials needed:

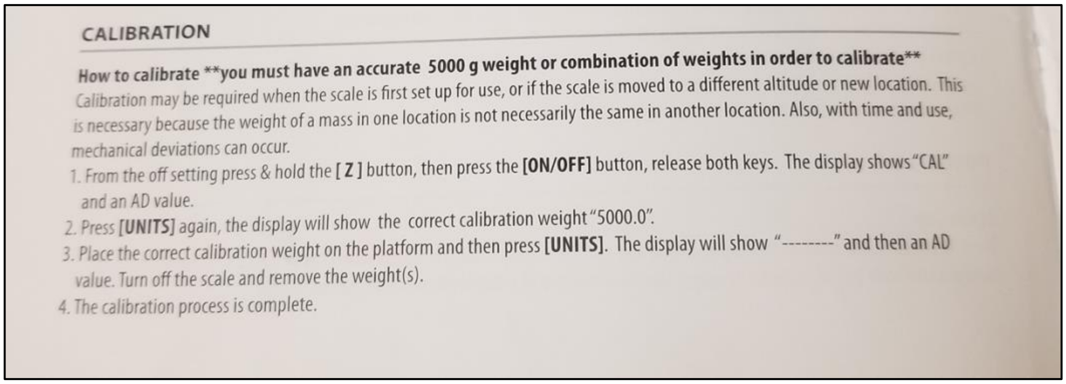
- *Calibrated 2kg weight*

Interval:
1 year

Procedure:
The digital scale should be characterized to ensure weight measurements are accurate. Note that a calibration report is not required to be created for this. This is considered "maintenance" in the *SWP_EquipmentRecords* spreadsheet for procedural purposes, and therefore is listed in the checks and maintenance section.

Figure 8. A scale used for SWP testing

Follow the instructions in the user's manual to recalibrate the digital scale, as the photo below shows.



CALIBRATION

How to calibrate **you must have an accurate 5000 g weight or combination of weights in order to calibrate**
Calibration may be required when the scale is first set up for use, or if the scale is moved to a different altitude or new location. This is necessary because the weight of a mass in one location is not necessarily the same in another location. Also, with time and use, mechanical deviations can occur.

1. From the off setting press & hold the **[Z]** button, then press the **[ON/OFF]** button, release both keys. The display shows "CAL" and an AD value.
2. Press **[UNITS]** again, the display will show the correct calibration weight "5000.0".
3. Place the correct calibration weight on the platform and then press **[UNITS]**. The display will show "--------" and then an AD value. Turn off the scale and remove the weight(s).
4. The calibration process is complete.

Figure 9. Scale user manual instructions for re-calibration.

Update the *SWP_EquipmentRecords* spreadsheet and label the scale with a calibration sticker and include your initials and date.

Angle Wood for strain relief

<u>*Materials needed:*</u>

- *Calibrated meter stick*
- *(maybe) protractor*

<u>*Interval:*</u>
As needed

<u>*Procedure:*</u>
Once this custom equipment has been built, it must only be checked once a year or as needed for any physical degradation or damage. If any damage or degradation is observed, it may indicate that this equipment will need to be replaced. If replacement is needed, use a calibrated meter stick to measure the lengths of wood needing to be connected and double check the angles made between each piece of wood using a protractor.

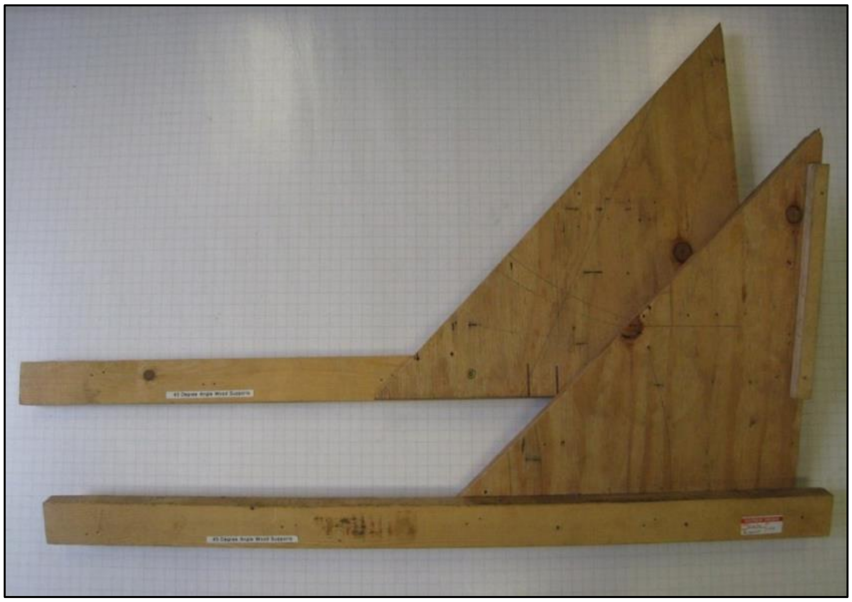


Figure 10. Custom angled wood cuts for strain relief.

DAQ voltage and current calibration

Materials needed:

- *Stopwatch*

Interval:

1 year

Procedure:

There is a voltage and current offset for the DAQ that will need to either be zeroed out in LabView or in the testing templates. The way our test lab handles these offsets (meaning that at a power input of zero, LabView reads a voltage and/or current not equal to zero) is account for them when we take measurements. Please follow the steps below for calibrating our test bench so that more accurate measurements may be taken:

1. Plug in the DAQ equipment, and plug in the Chroma. Make sure all lights indicate that everything is ON but **there is no power input on. Chroma is on but not providing any power—its output is off.**
    a. Note: the Chroma software does not need to be opened on the laptop.
2. Open LabView; set the ball valve to manual and set it to 100%. Open and write a new file for 20 minutes with all equipment on but no power input.
3. After 20 minutes, close out all software / windows on the laptop and turn everything off/ unplug DAQ. Then, repeat steps 1-3.
4. Repeat this five times over the course of approximately one hour, then copy/ paste all data from the five files into an Excel Sheet.
5. In Excel, average the voltage and current measurements for 20 minutes for each trial. Then, average all the voltage averages and current averages in an empty Excel sheet to determine the offsets.

6. Input the offsets (averages) into each testing template in the input tab where it says "offsets used" (see figures below).

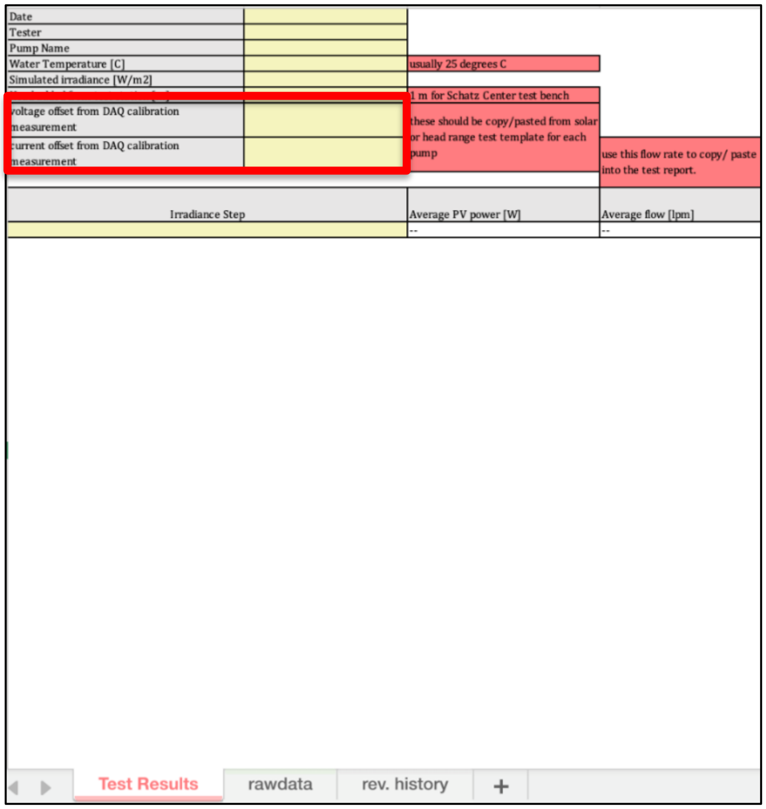
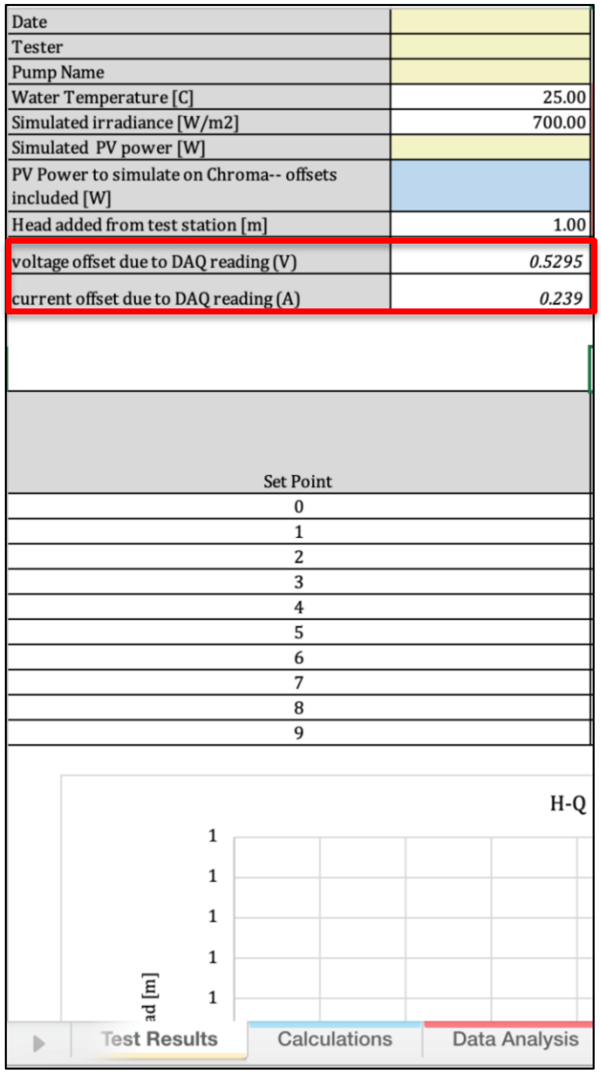


Figure 11. Cold start testing template, add offsets.

Above is the *ColdStart* test template in the *Test Results* tab, which is where the voltage and current offsets should be updated (highlighted within the red square).



Date	
Tester	
Pump Name	
Water Temperature [C]	25.00
Simulated irradiance [W/m2]	700.00
Simulated PV power [W]	
PV Power to simulate on Chroma-- offsets included [W]	
Head added from test station [m]	1.00
voltage offset due to DAQ reading (V)	*0.5295*
current offset due to DAQ reading (A)	*0.239*

Set Point
0
1
2
3
4
5
6
7
8
9

Figure 12. HeadRange testing template, add offsets.

Above is the *HeadRange* test template in the *Test Results* tab, which is where the voltage and current offsets should be updated in the red square.

TABLE 1. Initial inputs		
Inputs		notes
PV temperature coefficient (%/◦C)	-0.35%	This means that for every 1 degree Celsius , the PV panel will decrease in efficiency by this percentage. If the temperature coeff isn't provided, use the Table to the right to assume a value for this calculation.
P_{max} at STC (W)		--
Vmax		V
Imax		A
FOB cost		WITHOUT the PV module (if possible)
Retail Cost	$ -	*note, this is the cost WITHOUT the PV module. IF retail price is given (instead of FOB), overwrite formula to the left in col. B and input retail cost provided.
Simulated head [m]		
vertical distance added by the test bench	1	[illegible] if the test set up is changed or using a different test bench. This accounts for the vertical distance from the surface of the source water up to the inlet to the test bench pipe network.
$/W	*0.81*	CLASP guidance
PV module cost	$ -	delete if PV modules are already included in system cost
STC Temperature (degrees C)	25	--
TMOT temperature (degrees C)	50	--
change in temperature (degrees C)	25	--
efficiency loss from STC to TMOT (%)	-9%	--
Vmax, calculated (50 degrees C) (V)	--	Calculated. Use this to input into test report template.
Imax, calculated (50 degrees C) (A)	--	Calculated. Use this to input into test report template.
P_{TMOT}, calculated (50 degrees C) (W)	**0.00**	Calculated. Use this to input into test report template.
Vmax, calculated (50 degrees C) (V), **with offset**	--	Use this when testing. Still be aware if the Voc based on this Vmp will exceed system or product capabilities and make adjustments when possible so that these boundaries are not exceeded. This value not to be added to test report.
P_{TMOT}, calculated (50 degrees C) (W), **with offsets**	--	Use this when testing- this will be the simulated max power in the Chroma. This value not to be added to test report.
Voltage offset for the DAQ measurements (V)	***0.9000***	*These shouldn't be changed often unless more than 6 months has gone since using the test bench by or the DAQ has been updated. Ensure these match the other testing templates and the most recently saved calibration spreadsheet for the DAQ voltage and current offsets (copy and paste these values in from the dAQ current/voltage calibration spreadsheet) .*
Current offset for the DAQ measurements (A)	***0.230***	

Below, fill in the yellow cells with data from testing.

Instructions | Test Results | Inputs | PQ_Solver | Adjustment | High Irradiance

Figure 13. IrradianceData testing template, add offsets.

Above is the *IrradianceData* (Solar Day) test template in the *Inputs* Tab on Table 1, which is where the voltage and current offsets should be updated in the red square.

DAQ Pressure Offset

Materials needed:

- *Fluke 287 digital multimeter*
- *Stopwatch*
- *(2) Banana plug adapters*
- *WAGOs*
- *A SWP that can achieve high pressures (100-130psi), if possible, and has continuous/ stable output (submersible pump recommended)*

The calibrated pressure transducer in-line with the PVC network on the test bench outputs a current signal that is correlated to its pressure reading; LabView outputs measurements for pressure in psi, which is delivered by the DAQ equipment connected to the pressure transducer. To determine if the LabView pressure output remains accurate overtime, it must be characterized once a year to determine an offset to apply within the testing spreadsheets for all pressure readings to ensure accuracy of results.

Follow the steps below to perform this procedure:

1. Gather all needed materials; ensure the banana plug adapter has been wired in order to connect the Fluke DMM to the pressure transducer leads and test bench for this procedure. 18 AWG wire should be sufficient for this adapter.

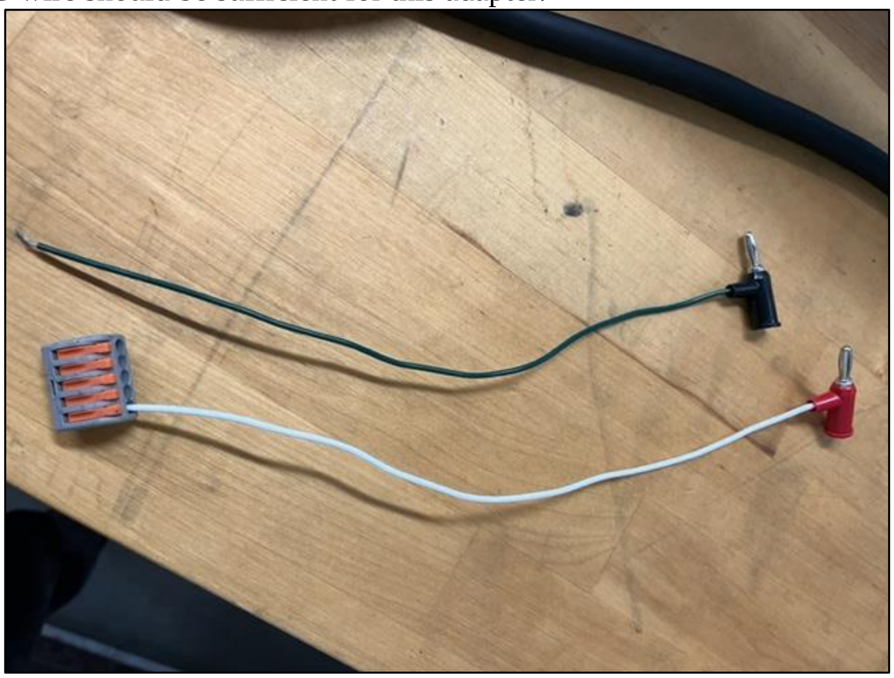


Figure 14. Banana plug adapter.

2. **Before starting this test, ensure that the Chroma unit is turned OFF and that the DAQ is not plugged into power, if possible, because this procedure entails handling bare wire in the test bench and could potentially become a safety hazard.**
3. Remove the cap of the wire ducting framing in the section of framing that holds the pressure transducer's leads connecting to the DAQ. You can trace the leads from the pressure transducer through the framing to the WAGO it is connected to within the ducting.

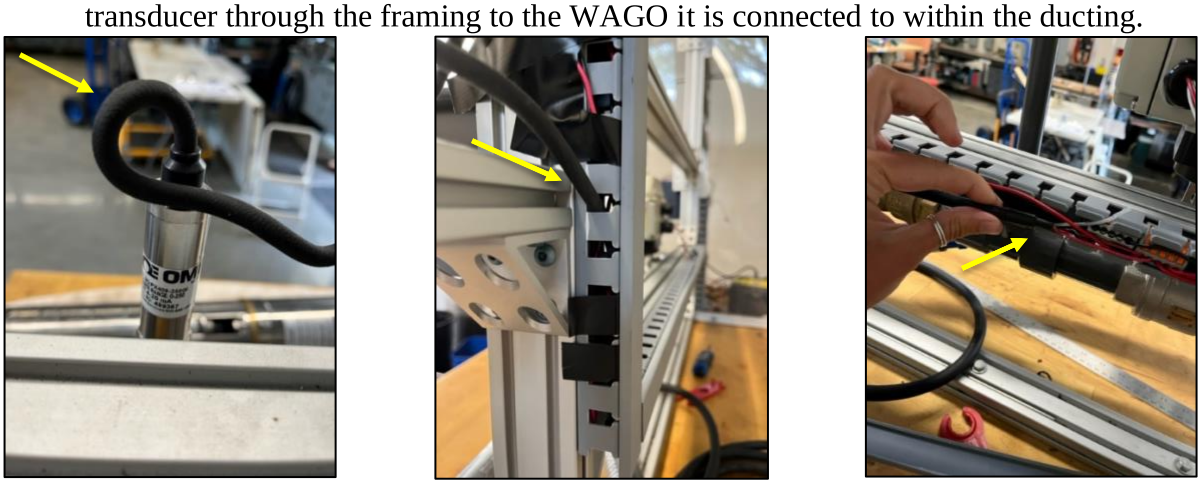


Figure 15. Following the pressure transducer all of the way through the ducting to the first WAGO connection.

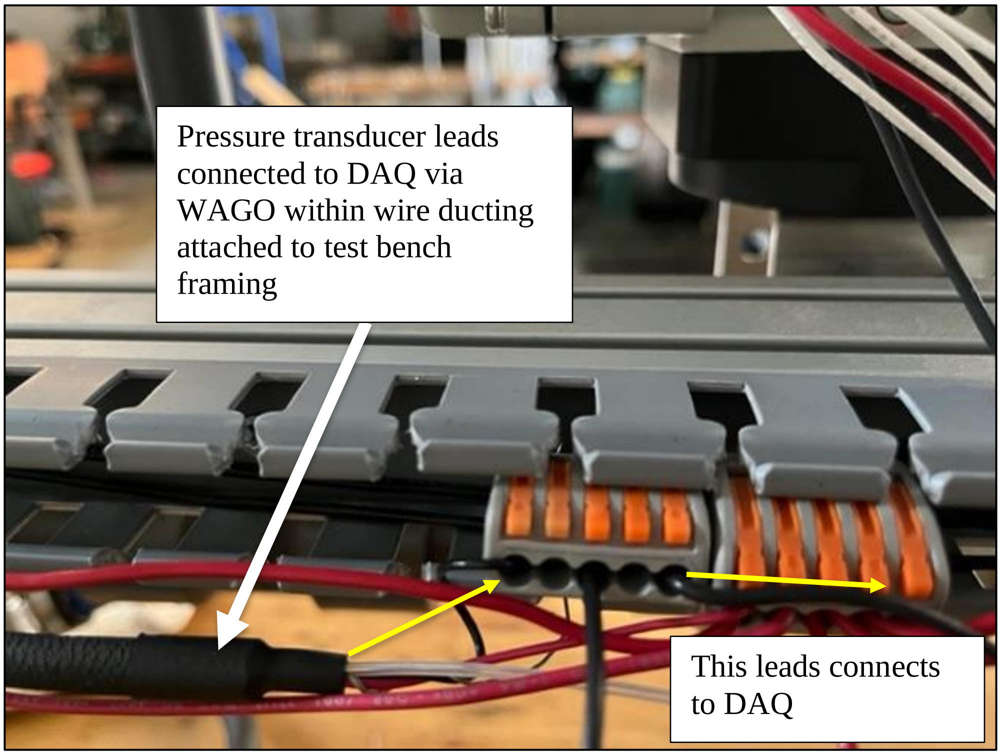


Figure 16. Pressure transducer leads connected to the first WAGO.

4. The Fluke DMM will need to be wired in series to the negative lead of the pressure transducer to measure its output current during this procedure. Steps 5-7 describe how to achieve this configuration for calibration.
5. Carefully, remove the negative lead of the pressure transducer from the WAGO and connect it to an empty WAGO.

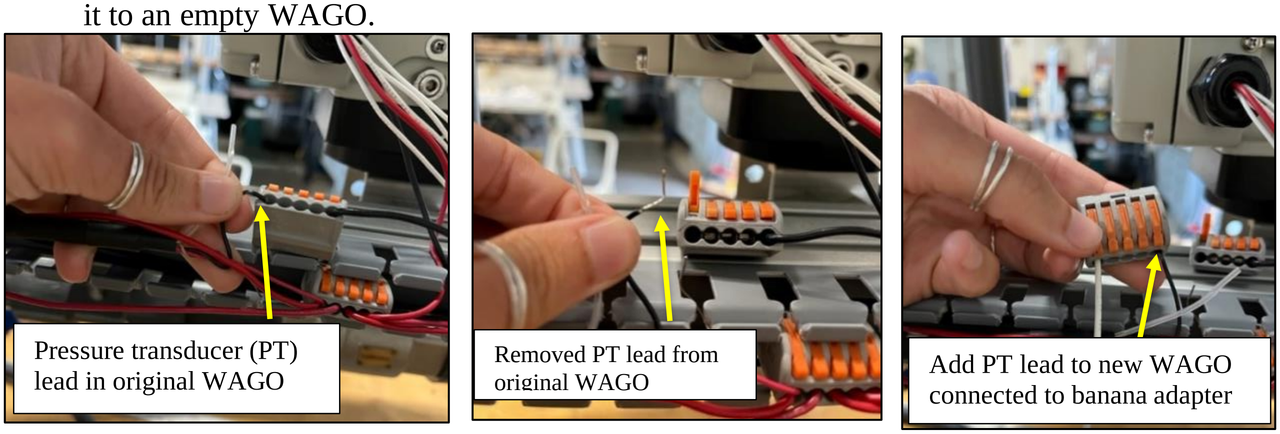


Figure 17. Removing the negative pressure transducer lead from the original first WAGO and connecting it to a new WAGO also connected to a banana plug adapter that is plugged into the Fluke DMM.

6. Connect the WAGO that now only holds the negative pressure transducer lead to the wire-end of one banana plug adapter. The banana-plug-end of the adapter should be plugged into the positive (red) side of the Fluke in the 400mA port for reading current (mA).

Figure 18. Fluke DMM on mA setting with the banana plug adapters plugged into the COM and 10A fuse ports (note the 400mA fuse port should be used in place of the 10A fuse if the mA reading using the 10A fuse is <400mA).

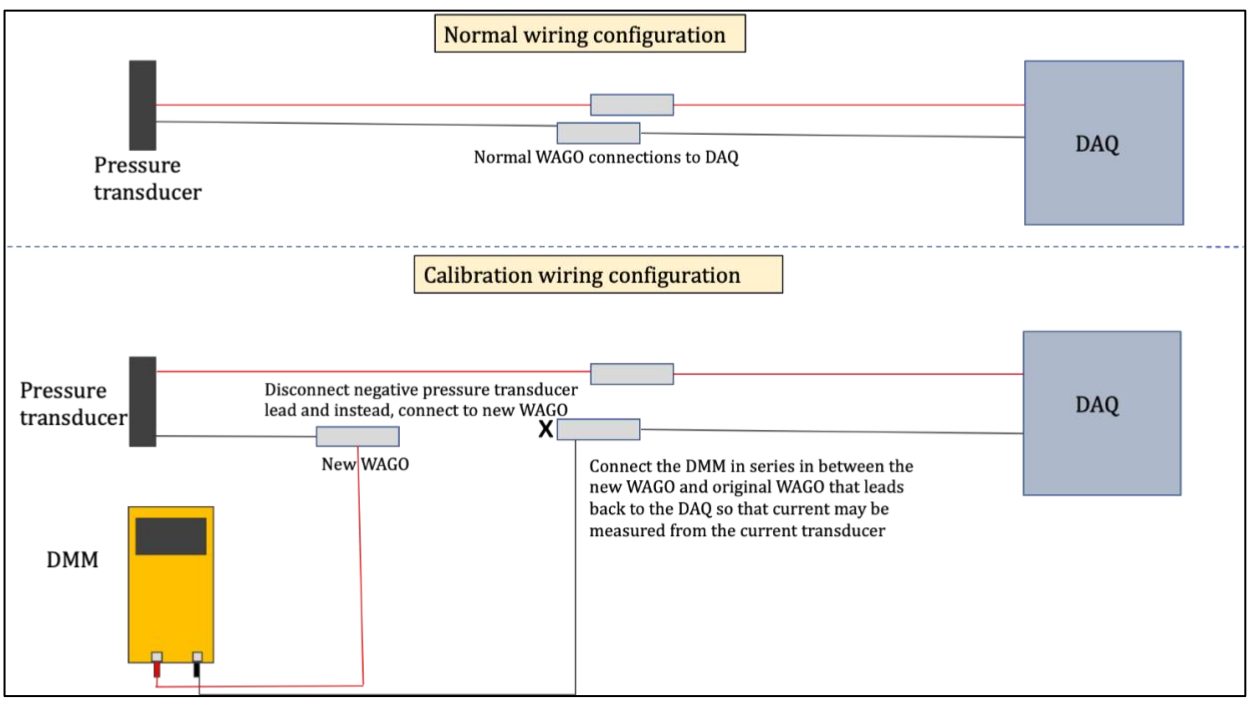


Figure 19. Diagram of the calibration set up.

7. Plug in the second banana plug adapter into the negative (black) COM port of the multimeter, and connect the stripped wire-end of the adapter into the original WAGO that used to be connected to the negative lead of the pressure transducer.

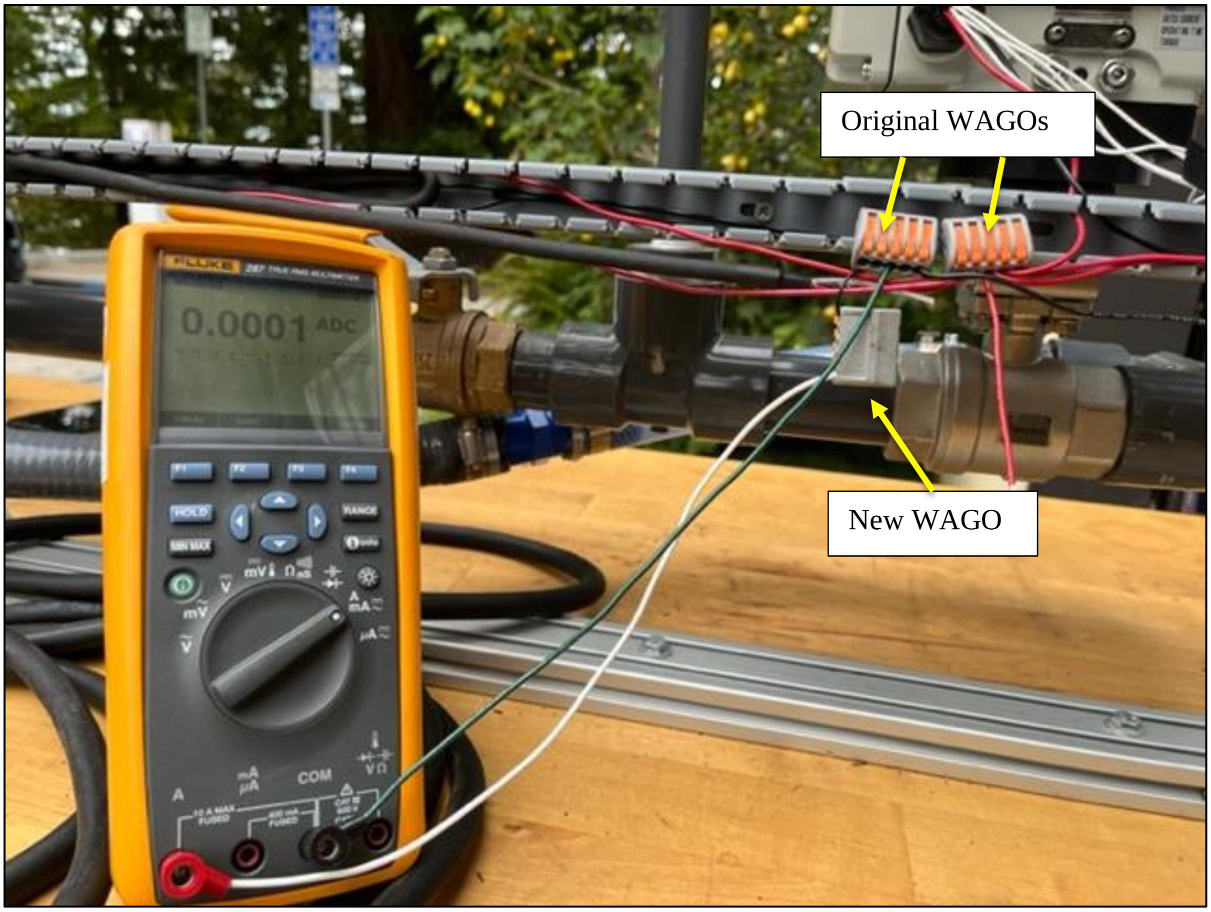


Figure 20. Fluke DMM connected in series with the negative pressure transducer lead and DAQ to measure in-line current.

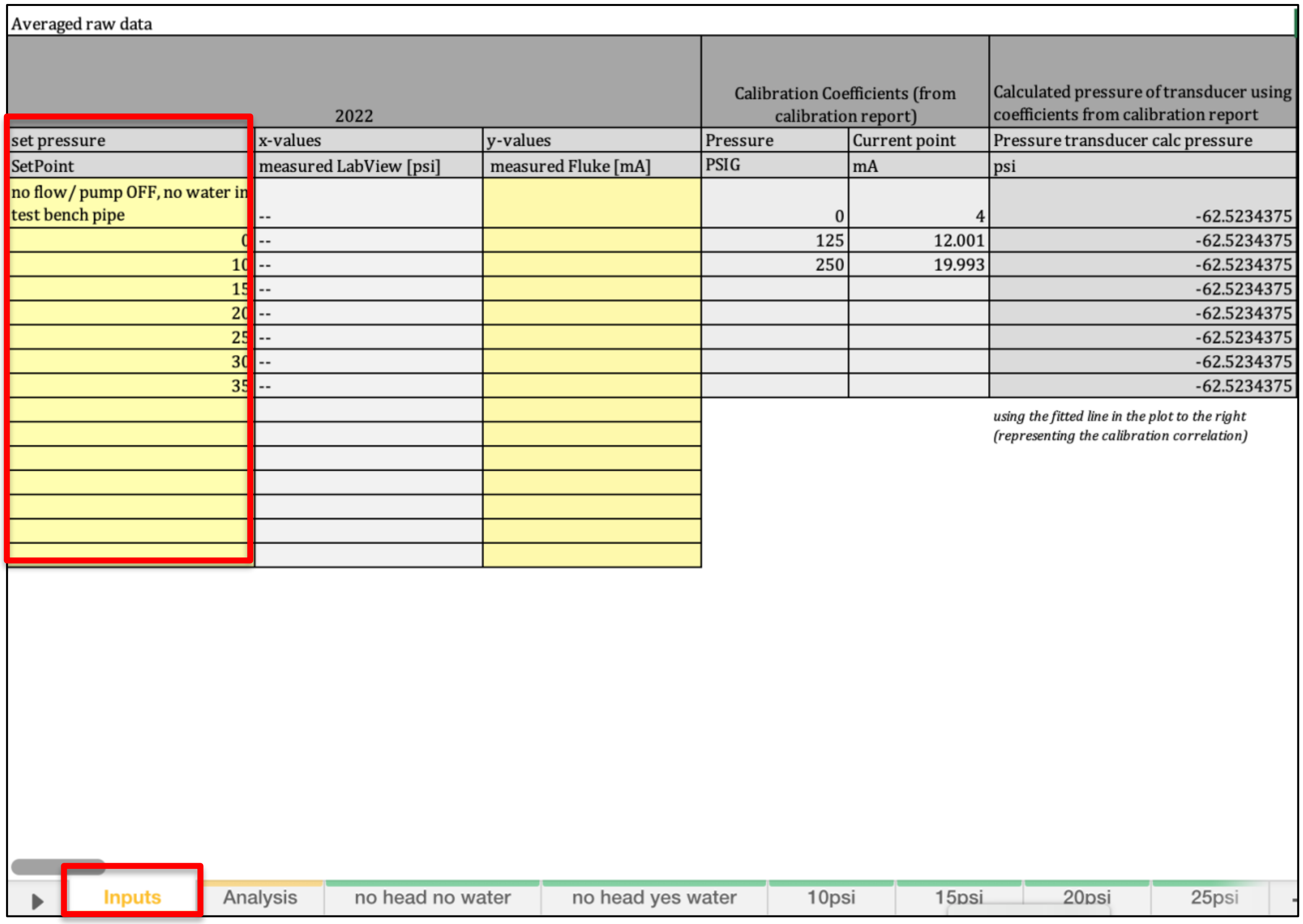
8. Once the fluke is fully connected, you may set up the SWP chosen for performing this procedure. Choose a SWP that was tested at your lab and wasn't damaged upon testing or opened during the internal inspection; if there is a functional SWP that can achieve higher pressures (100-130psi) and has a stable output, then this would be recommended.
9. After the pump is wired up, following the instructions in manufacturer-provided information for testing, you may plug in the DAQ and turn the Chroma unit ON. Follow steps 7-21 and step 31 in the *6 SWP SolarDayTest SOP* to open LabView and the Chroma software and read in the I-V curves (should have been saved previously during testing of the pump).
10. Read in the step associated with the 1000 W/m2 irradiance step in the Chroma software; double check it corresponds to the *IrradianceData* testing spreadsheet that had been filled in for the pump during previous testing. Ensure none of the voltage or current or power set points surpass the pump's rated input limits.
11. Use the Pressure Transducer characterization template enter data during this procedure.
12. Create a new subfolder to save this characterization spreadsheet, and name it the current year so that each year's calibration data is organized by when they were saved/ performed.
13. Within the subfolder, copy and paste in the *DAQ Pressure Characterization Template* spreadsheet and update the filename so that it is saved in the following format: *DAQ Pressure Characterization-ddmmyy-testers initials*

14. Open the file and start on the *Inputs* tab.
15. Fill out the light-yellow cells in the *General Info* table to specify today's day, which pump was used for characterization, the testers, what equipment was used for measurement, the transducer characterized, the input power setpoint on the Chroma (this is Pmax at 1000 W/m2 used), and the simulated irradiance step (most cases should be 1000 W/m2).

General info	
Date	
Pump used for characterization	
Testers	
Fluke used	
Transducer characterized	
Input Power setpoints (on Chroma)	
Simulated Irradiance Step	

Figure 21. General info table in the *Inputs* tab within the *DAQ Pressure Characterization Template*.

16. Determine the pressure setpoints (psi) to simulate for this procedure. Generally, this will depend upon the pump that is being used for this procedure and how much pressure can be achieved by it. Note that the two lowest points should always be "no flow/ pump off, no water in test bench pipe" and 0psi.
    a. Include as many points as reasonable; see the figure below as an example of a pump that can achieve up to a pressure of 35psi.
    b. Fill in the simulated pressure points determined in the table within the Inputs tab of the spreadsheet in the leftmost column.



Averaged raw data

			Calibration Coefficients (from calibration report)		Calculated pressure of transducer using coefficients from calibration report
	2022				
set pressure	x-values	y-values	Pressure	Current point	Pressure transducer calc pressure
SetPoint	measured LabView [psi]	measured Fluke [mA]	PSIG	mA	psi
no flow/ pump OFF, no water in test bench pipe	--		0	4	-62.5234375
0	--		125	12.001	-62.5234375
10	--		250	19.993	-62.5234375
15	--				-62.5234375
20	--				-62.5234375
25	--				-62.5234375
30	--				-62.5234375
35	--				-62.5234375

using the fitted line in the plot to the right (representing the calibration correlation)

Inputs | Analysis | no head no water | no head yes water | 10psi | 15psi | 20psi | 25psi

Figure 22. Inputting pressure setpoints in the calibration spreadsheet, which corresponds to the chosen pump's capacity.

17. It might make sense (and be necessary) to have two testers conduct the measurement-taking portion of this procedure because at each pressure setpoint, data will be recorded starting at the exact same time over the course of one minute in LabView and on the DMM. If the DMM is set up and cannot be reached by the tester on the laptop (which has been the case), it would make sense to assign one tester to DMM measurement recordings and one to LabView recordings.
18. Ensure the Fluke is on the mA setting.

Figure 23. Fluke DMM in the mA setting with banana plug adapters already plugged in.

19. Start at the lowest pressure setpoint.
20. Ensure the Chroma software has read in the Pmax associated with the 1000 W/m2 irradiance step for the chosen pump for this procedure. Ensure the high flow ball valve is fully open. Turn the Chroma output ON to provide power to the pump (UNLESS this is the no flow/ pump OFF step).
    a. For the “no flow/ pump OFF, no water in test bench pipe” step, the Chroma output should remain OFF (the pump shouldn’t have any input power).
21. Let the pump stabilize for a few minutes.
    a. UNLESS at the “no flow/ pump OFF” step. There is no stabilization period for this first step.
22. Adjust the high flow ball valve (or low flow ball valve if the flow output is under 25 lpm) until the target pressure being read in LabView is as close to the setpoint you are simulating as possible (see exceptions below).
    a. At the no flow/ pump OFF and 0psi steps, the high flow ball valve should remain fully open.
23. When the SWP is stable and the pressure the pressure of the system is as close to the pressure setpoint as possible, open a data file on LabView labeled with the set point being simulated, and at the same time, hit the MIN MAX button on the Fluke in series with the pressure transducer negative lead. Record on both devices for approximately one minute.

Figure 24. MIN MAX button on the Fluke DMM.

24. At one minute, press HOLD on the Fluke at the same time as closing the file being read on LabView.
    a. Record the average measurement (you may write this down on paper specify which pressure set point was used).
        i. Ensure to look at the min/ max measurements as well to see if there were any measurements out of the expected current range.

Figure 25. HOLD button on the Fluke DMM and the average measured value over the time interval in the yellow rectangle.

   b. Find the raw data file from that minute of recording from LabView on the computer and drop it in the pressure transducer characterization subfolder for the current year.

25. Move onto the next pressure setpoint; repeat steps 22-24 for each pressure set point. The Chroma may remain on, powering the pump at 1000 W/m2, over the course of this procedure.
    a. Remember to start taking measurements from the low flowmeter and adjusting the low flow ball valve for all measurements where the flowrate is less than 25 lpm.
26. After all of the pressure setpoints have been simulated, and the data from LabView and from the Fluke has been recorded and saved, turn the Chroma output OFF and turn the unit OFF and start putting the test bench away.
27. Use the *DAQ Pressure Characterization* spreadsheet to analyze all raw data.
28. First, input all raw data into the spreadsheet.
    a. Input all of the Fluke pressure transducer current measurements that were written down on paper into the "Inputs" tab in the spreadsheet.

Averaged raw data

2022			Calibration Coefficients (from calibration report)		Calculated pressure of transducer using coefficients from calibration report
set pressure	x-values	y-values	Pressure	Current point	Pressure transducer calc pressure
SetPoint	measured LabView [psi]	measured Fluke [mA]	PSIG	mA	psi
no flow/ pump OFF, no water in test bench pipe	-0.49	3.974	0	4	-0.4296875
0	7.83	4.507	125	12.001	7.8984375
10	10.00	4.645	250	19.993	10.0546875
15	15.03	4.967			15.0859375
20	20.02	5.288			20.1015625
25	25.18	5.618			25.2578125
30	30.10	5.932			30.1640625
35	35.02	6.246			35.0703125

using the fitted line in the plot to the right (representing the calibration correlation)

Figure 26. Manually input measured Fluke average current measurement for each pressure setpoint from the procedure into the calibration spreadsheet.

b. Copy and paste the raw data files generated by LabView into each green raw data tab. Paste in the first column so that the equation in column V in each raw data tab will automatically populate.

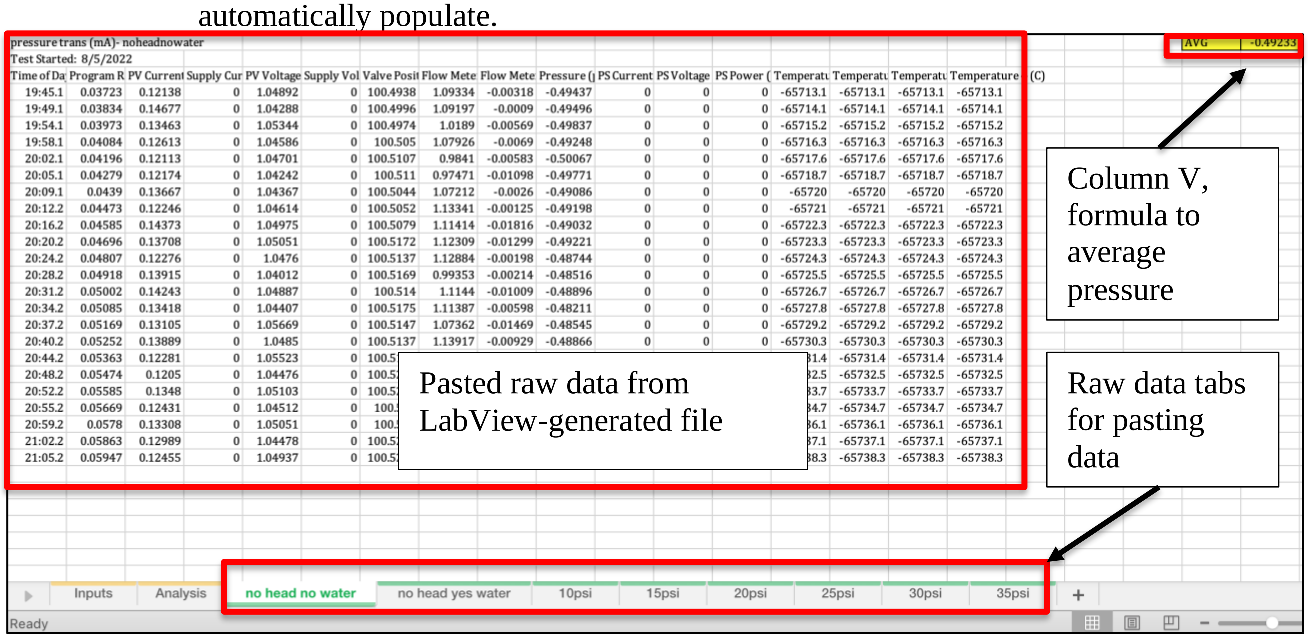


Figure 27. For the measurements taken by LabView, copy and paste raw data from the data files into the raw data green tabs in the calibration spreadsheet.

c. Note that column V should always be checked for each raw data tab to ensure all of the data is being selected in the formula and that the formula is referencing the correct column of raw data.

d. Column V will then automatically populate the table in the "Inputs" tab for the measured LabView measurements (see photo below).

Averaged raw data

2022			Calibration Coefficients (from calibration report)		Calculated pressure of transducer using coefficients from calibration report
set pressure	x-values	y-values	Pressure	Current point	Pressure transducer calc pressure
SetPoint	measured LabView [psi]	measured Fluke [mA]	PSIG	mA	psi
no flow/ pump OFF, no water in test bench pipe	-0.49	3.974	0	4	-0.4296875
0	7.83	4.507	125	12.001	7.8984375
10	10.00	4.645	250	19.993	10.0546875
15	15.03	4.967			15.0859375
20	20.02	5.288			20.1015625
25	25.18	5.618			25.2578125
30	30.10	5.932			30.1640625
35	35.02	6.246			35.0703125
					using the fitted line in the plot to the right (representing the calibration correlation)

Figure 28. After some adjustment in the raw data tabs in the calibration spreadsheet, the averages should populate in the *Inputs* tab for the measured LabView data for each pressure set point.

e. Ensure the formulas in the column in the red square above reference all of the raw data tabs. Depending on what pump is chosen each time this characterization is performed, there might be different numbers of pressure setpoints, so ensure this column populates with the average pressure measured in LabView for each setpoint.

f. You may have to add more raw data tabs and expand the formulas if more setpoints are recorded than the default in the spreadsheet template.

29. In the *Inputs* tab table, there are two grey columns that should only be updated if the pressure transducer itself is sent out for calibration. The values in these two columns are pulled directly from the calibration report from the accredited third-party lab. These points specify the relationship between the current measurements from the pressure transducer and the pressure associated.

    a. Note that these values from the calibration report are needed so that the current measurements taken with the fluke may be converted into pressure readings. The relationship between current and pressure is needed for this calculation.

Averaged raw data

	2022		Calibration Coefficients (from calibration report)		Calculated pressure of transducer using coefficients from calibration report
set pressure	x-values	y-values	Pressure	Current point	Pressure transducer calc pressure
SetPoint	measured LabView [psi]	measured Fluke [mA]	PSIG	mA	psi
no flow/ pump OFF, no water in test bench pipe	-0.49	3.974	0	4	-0.4296875
0	7.83	4.507	125	12.001	7.8984375
10	10.00	4.645	250	19.993	10.0546875
15	15.03	4.967			15.0859375
20	20.02	5.288			20.1015625
25	25.18	5.618			25.2578125
30	30.10	5.932			30.1640625
35	35.02	6.246			35.0703125

using the fitted line in the plot to the right (representing the calibration correlation)

Figure 29. The values in the red rectangle were taken directly from the pressure transducer's most updated calibration report when it was first calibrated upon its purchase.

30. The last right column in the table (figure above) in the "Inputs" tab of the spreadsheet contains a formula to convert the fluke current measurements in the third column into pressure so that they can be compared to the pressures measured in LabView.
    a. This formula should only be changed if the pressure transducer is sent out for calibration and has new calibration coefficients. If this is the case, follow these steps:
        i. Plot the calibration coefficients taken from the pressure transducer's most recent calibration report. Pressure should be plotted on the x-axis and current on the y-axis.
        ii. Fit a line to the plotted points and set the trendline
        iii. The trendline is the formula used in the calculation in the last column to convert mA to psi. Solve for x, pressure, with the formula.

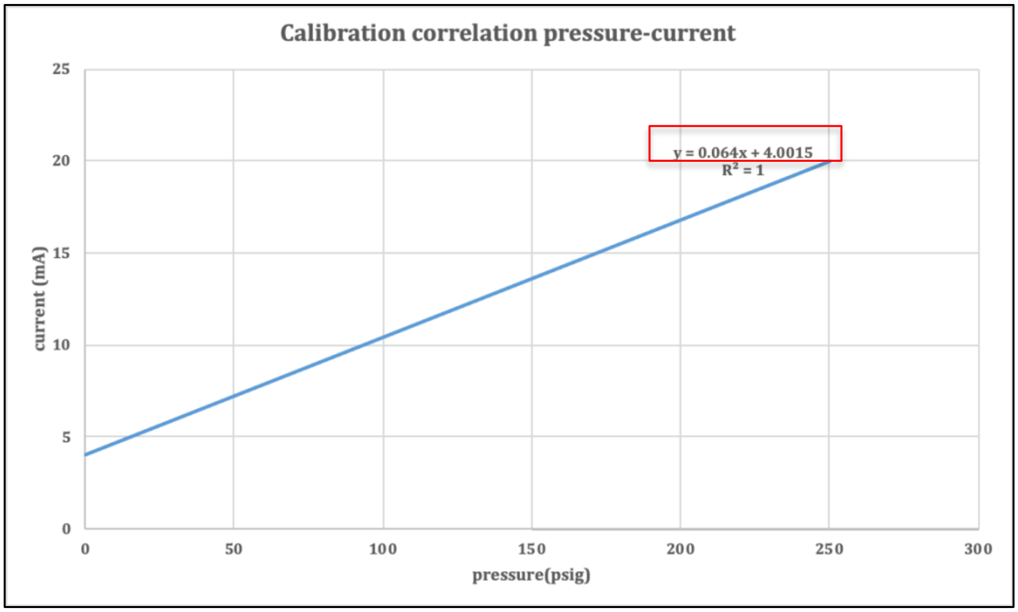


Figure 30. The linear relationship between psi and mA is the formula used to calculate psi from the Fluke's mA readings so they can be compared to what LabView measured during the procedure.

31. Next, navigate to the *Analysis* tab in the spreadsheet. Calculate the average flowrate at each pressure setpoint using the raw data logged by LabView to input into the table in this tab.
    a. Make sure to use the correct flowmeter's data.
32. Fill in the coefficient and slope for the trendline generated by the calibration report data in the *Inputs* tab.

coefficients from Pressure Transducer calibration report:	slope of line from calibration report:	0.064	intercept of line from calibration report:	4.0015

Step (psi)	Q [lpm] (measured by DAQ for each step)	P_1 [psi] (calculated by Pressure Transducer calibration report)	P_0 [psi] (measured psi from LabView DAQ)	Δ P [psi]	Δ P[m] (convert psi to meters of head)	ΔP - ΔP0 (psi) (where P0 is the pressure of system with no flow)	ΔP - ΔP0 (psi) (b)	
no flow/ pump OFF	1.08	-0.43	-0.49	-0.06	-0.0441			
0	167.50	7.90	7.83	-0.07	-0.048	-0.01		removing outliers fro
10	157.79	10.05	10.00	-0.05	-0.04	0.01	0.01	
15	126.76	15.09	15.03	-0.06	-0.04	0.00	0.00	
20	89.45	20.10	20.02	-0.08	-0.06	-0.02		
25	57.73	25.26	25.18	-0.08	-0.06	-0.02		
30	31.06	30.16	30.10	-0.06	-0.04	0.00	0.00	
35	6.97	35.07	35.02	-0.06	-0.04	0.01	0.01	

Figure 31. *Analysis* tab in the calibration spreadsheet. The average flow for each pressure setpoint measured in LabView must be filled out and the coefficients from the trendline formed with data from the pressure transducer calibration report found in the *Inputs* tab also needs to be entered in this tab.

33. The grey cells are formulas, which are described in the header of each. The very last column will require user input; the outliers will need to be removed in this column in order to perform a least squares regression on the data to check it.
34. Plot the flowrate against the change in pressure (the fifth column). This plot should already be present; you may just need to adjust the references. Fit a line of best fit to the data.

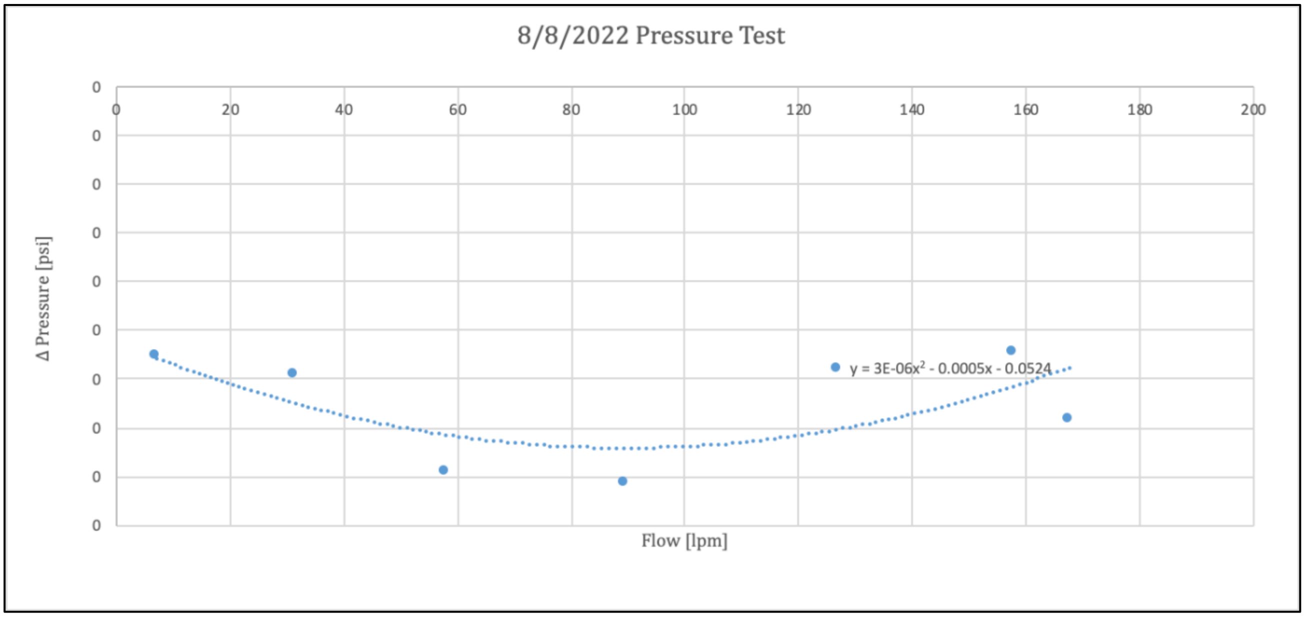


Figure 32. Plotting the raw data of average flow and change in pressure for each pressure setpoint to find an equation.

35. Plot the flow versus the change in pressure due to flow (the red column below) without the measured outliers. Add an exponential trendline to the data (or one of best fit).

				coefficients from Pressure Transducer calibration report:	slope of line from calibration report:	0.064	intercept of line from calibration report:	4.0015
Step (psi)	Q [lpm] (measured by DAQ for each step)	P_1 [psi] (calculated by Pressure Transducer calibration report)	P_0 [psi] (measured psi from LabView DAQ)	Δ P [psi]	Δ P[m] (convert psi to meters of head)	ΔP - ΔP0 (psi) (where P0 is the pressure of system with no flow)	ΔP - ΔP0 (psi) (b)	
no flow/ pump OFF,	1.08	-0.43	-0.49	-0.06	-0.0441			
0	167.50	7.90	7.83	-0.07	-0.048	-0.01		removing outliers fro
10	157.79	10.05	10.00	-0.05	-0.04	0.01	0.01	
15	126.76	15.09	15.03	-0.06	-0.04	0.00	0.00	
20	89.45	20.10	20.02	-0.08	-0.06	-0.02		
25	57.73	25.26	25.18	-0.08	-0.06	-0.02		
30	31.06	30.16	30.10	-0.06	-0.04	0.00	0.00	
35	6.97	35.07	35.02	-0.06	-0.04	0.01	0.01	

Figure 33. Use the average flowrate at each pressure setpoint and the pressure differential without outliers, determined when making the plot in Figure 33 above.

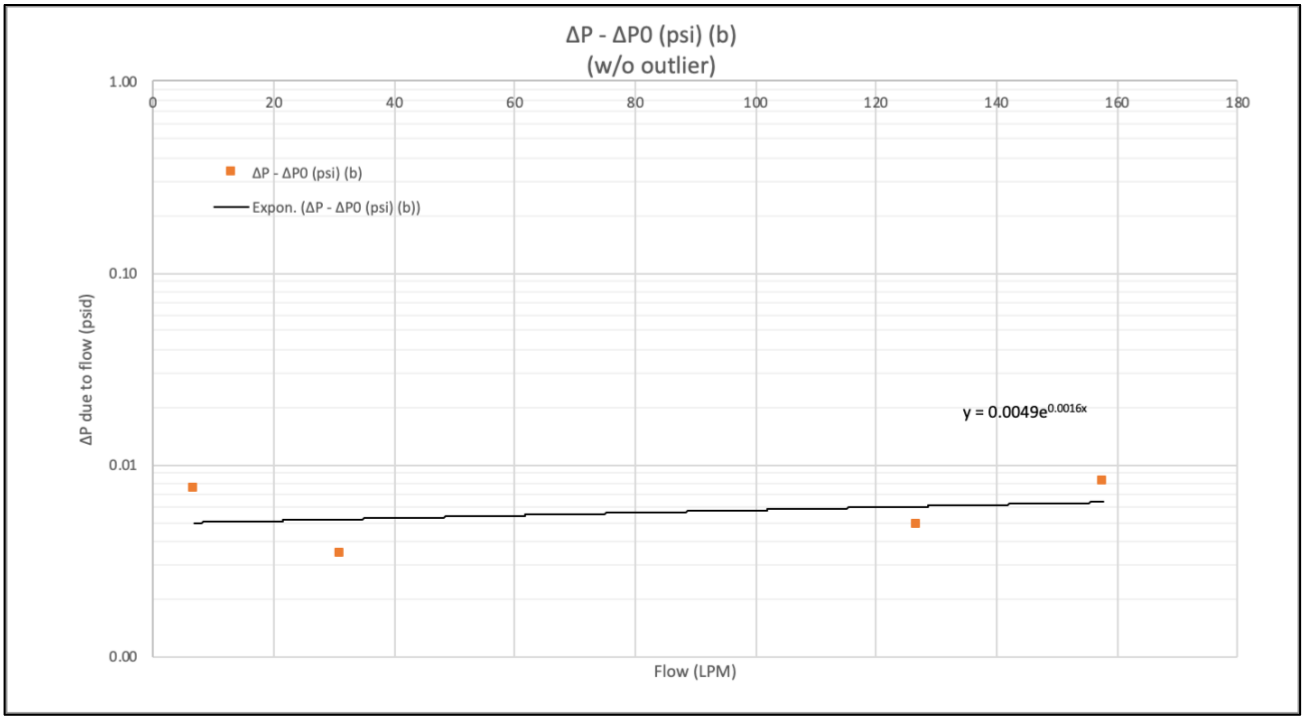


Figure 34. Flowrate versus the pressure differential with outliers removed.

36. You may decide to perform a least squares regression to check the data in the plot in step 35 above; this will double check that the exponential trendline chosen for the data matches the regression.
37. Next, open the *IrradianceData* template spreadsheet to make an update based upon this characterization.
38. Navigate to the *Adjustment* tab in the *IrradianceData* template spreadsheet. And scroll to the right to the "References used for calculation tables" section.

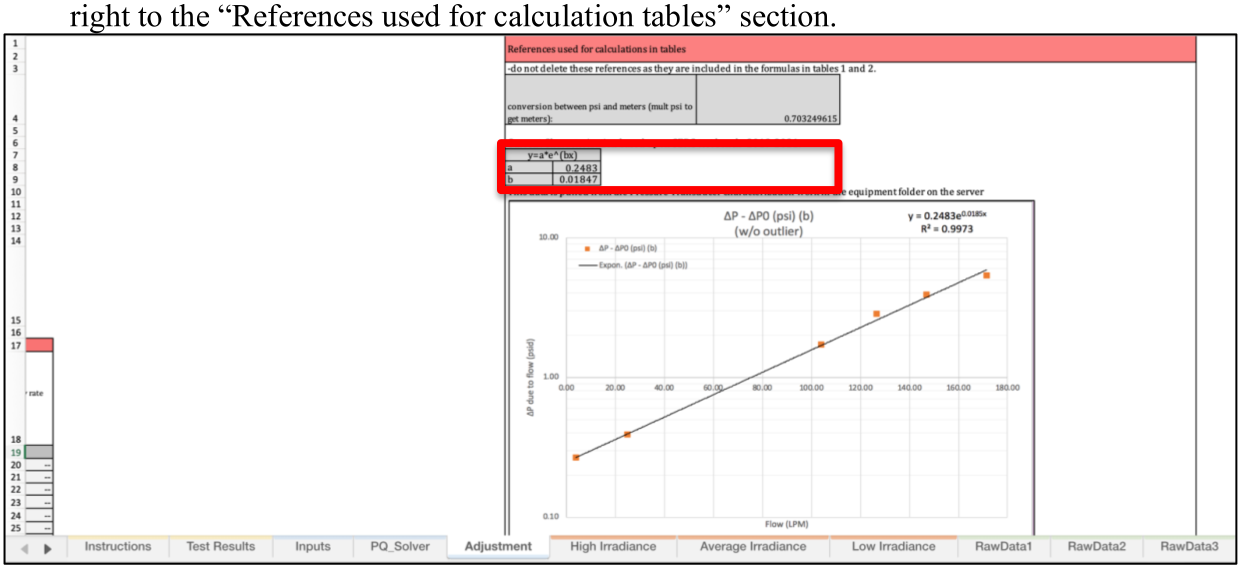


Figure 35. *IrradianceData* spreadsheet *Adjustment* tab, where the coefficient and slope from last plot made should be entered (in the red rectangle).

39. Copy the coefficient and slope from the last plot generated (in step 35) into the spaces for a and b in the *IrradianceData* template. For the example plot used in step 35, looking at the plot's trendline, a=0.0049 and b=0.0016, so these would overwrite the values currently there.
40. Save the new version of the *IrradianceData* template so these new values will be incorporated so that the reported pressure during testing is as close to the pressure transducer output measurement as possible.

Version	Date	Summary
1.0	8/31/22	First draft of this procedure.

Scope / Field of Application

Generally, all tests done on solar water pumps (SWPs) following the Global LEAP SWP Test Method, version 2, utilizes a solar array simulator (such as the Chroma) as a power source. Occasionally, a SWP under test will be incompatible with the Chroma; more research needs to be done regarding this issue; however, this issue appears to be related to programming response time and slew rate of the Chroma and the rate in which a pump's controller maximum power point algorithm functions to accept the best power inputs available along the I-V curve input. When a SWP is not compatible with the Chroma (more information below), the method outlined in this SOP should be carried out for all test bench tests required. The Alternative Test Method carries out all of the same procedures listed in the following SOPs; however, the Chroma is replaced as a power source with an actual PV array:

- *4 SWP Cold start and Inrush Current* SOP
- *5 SWP Head Range* SOP
- *6 SWP Solar Day* SOP
- *7 SWP Protections Tests and Full Tank* SOP
- *8 SWP Durability Tests* SOP

Additionally, the tester may follow the same instructions for testing set up for this method, which is outlined in the *1 SWP Testing Set Up SOP*, EXCEPT the instructions for the Chroma set up may be ignored since the Chroma will be replaced by an actual PV array for this method.

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customized by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

Maximum Power Point Tracking (MPPT)- A charge controller algorithm that searches for the maximum power point along the PV array's IV curve in order to maximize the power utilized from the PV array.

Hot spot- When a PV module is partially shaded, it can sometimes create an electrical short in one or more PV cells, which could create heat. When this occurs in a shaded cell (or more than one), this can result in a small region of the cell being damaged and shorting the whole cell, or generalized, which could damage the module insulation.

SWP- solar water pump

SOP- standard operating procedure

Responsibilities

SWP tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks, if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test results, and provides input as needed. Also, may communicate directly with the client, as needed.

Materials Required

- *SWP test bench*
- *PV modules that can be configured into an array that matches the rated Voc, Vmp, Isc, Imp, Pmp power inputs for the SWP*
  - *Usually several 250W or 300W PV modules if a larger PV array needs to be configured*
  - *Note: the size of the PV modules used for a SWP is dependent upon its rated input Pmax, Voc, and Isc calculated at TMOT.*
  - *Note: PV modules used should have grounding conductor already installed.*
- *Semi-clear material*
- *PV parallel-circuit adapter (if any PV modules need to be configured in parallel)*
- *MC4-to-wire adapters (male and female)*

Pre-Test Preparation

Before conducting any of the tests using the Alternative Test Method, the Intake and Visual Screening, the SWP wiring to the test bench, and the PV array configuration and wiring must have all been competed (as described in the procedure below). Additionally, the *IrradianceData* spreadsheet *Input* tab must be filled out so that each irradiance step has its associated, calculated input power determined.

Before this test is carried out, the following SOPs must be read and procedures carried out (if applicable) for the pump under test:

- *SWP Test Bench Instruction Manual*
- *1 SWP Testing Safety*
- *2 SWP Intake and Visual Screening*

Also, before conducting this test, PV modules will need to be identified at the test lab that are able to be used for these testing purposes. In the procedure below, there are instructions on how to determine the size and number of PV modules needed for a SWP. Ensure the PV modules have enough grounding conductors installed *correctly* in order to be able to properly ground the array, once determined and set up. Each PV module may have different instructions for how to install its grounding conductor, so this should be well-researched prior to installing. Additionally, several grounding conductors may need to be purchased for this.

Ensure all safety trainings have been provided to operate the test bench.

Procedure

Before setting up for testing, note that this procedure may require two testers for each test: one to adjust power input and one to record measurements and adjust the pressure of the test bench.

When to use this method

This method is carried out for all SWP tests that would normally require the use of the Chroma solar array simulator as the power input, and it is the method followed if the Chroma and the SWP are deemed incompatible. The *6 SWP Solar Day* SOP describes how to determine compatibility in *step 44* within that procedure.

Designing PV array

1. Before the PV array is set up for this method for testing, it should be designed based upon the maximum input power parameters specified by the SWP available materials, the calculated TMOT input power parameters calculated in the *IrradianceData* spreadsheet, the PV modules available at the test lab, and the physical, spatial limitations of where the PV array will be built.
2. The PV array inputs in this design should be close to the calculated TMOT power parameters from the *IrradianceData* spreadsheet, and they should not surpass the input restrictions of the SWP.
3. The Lab Manager should always review the PV array design before it is set up and used to test with.
4. For more information on how to plan a PV array for a SWP and for an example, see Appendix A below.

Wiring up PV array

5. After obtaining the PV modules and any adapters needed to configure a PV array that matches the input ratings to the SWP under test calculated to TMOT conditions, identify a sunny, flat space large enough to lay out the array. If the location receives limited full sunshine (not all day long), it makes sense to complete setting up the array in the early morning to allow for more time for testing once sunny.
    a. Ensure the space chosen is close to where the test bench normally tests so that it may be plugged into an outlet to power the DAQ.

Figure 1. Open, flat testing space. This picture was taken in the morning, before sun exposure, which was when testers set up for testing to maximize testing time in the direct sun.

6. Ensure the Chroma is OFF and the DAQ is not plugged in.
7. Roll the test bench out into the space and connect MC4-to-wire adapters to the power input terminal blocks.

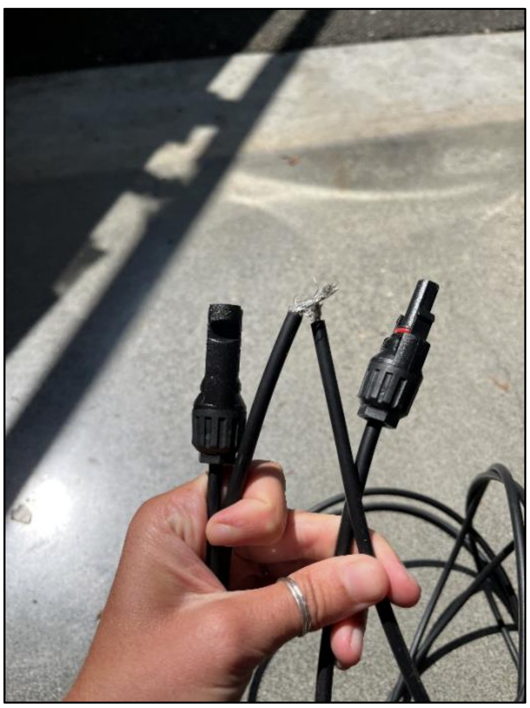


Figure 2. MC4-to-wire adapters

   b. Remove the Chroma output leads from the terminal block on the test bench surface.

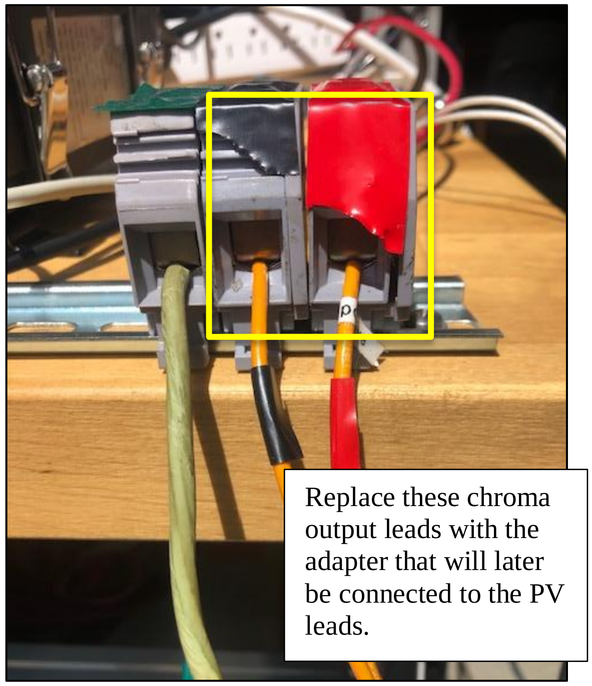


Figure 3. Chroma output lead screw terminal connection to extend to DAQ and SWP connection.

c. Replace the Chroma leads with the wire-end of the MC4-to-wire adapter, inserting the stripped bare wire end and using a flathead screw driver to clamp down on it within the enclosure.

d. Additionally, find an extension wire that is at least 13 AWG that can be connected to the grounding conductor affixed to the PV racking for each strand connected in series. Connect this wire/ wires to the grounding terminal on the same terminal block.

e. <u>Note: always wire the MC4-to-wire adapter to the test bench first and THEN connect the MC4 connectors of the PV array second to ensure you are not handling “hot” electrical wire when you make the screw terminal connection</u>.

8. If the PV modules only need to be wired in **<u>series</u>**, then follow these steps before connecting the array to the test bench:

   f. The PV modules may be wired up by connecting their MC4 connectors, leaving the positive lead of the “first” module and the negative lead of the “last module” disconnected so they can be wired up to the SWP test bench (which is the last set up step).

Figure 4. PV array set up in sunny space.

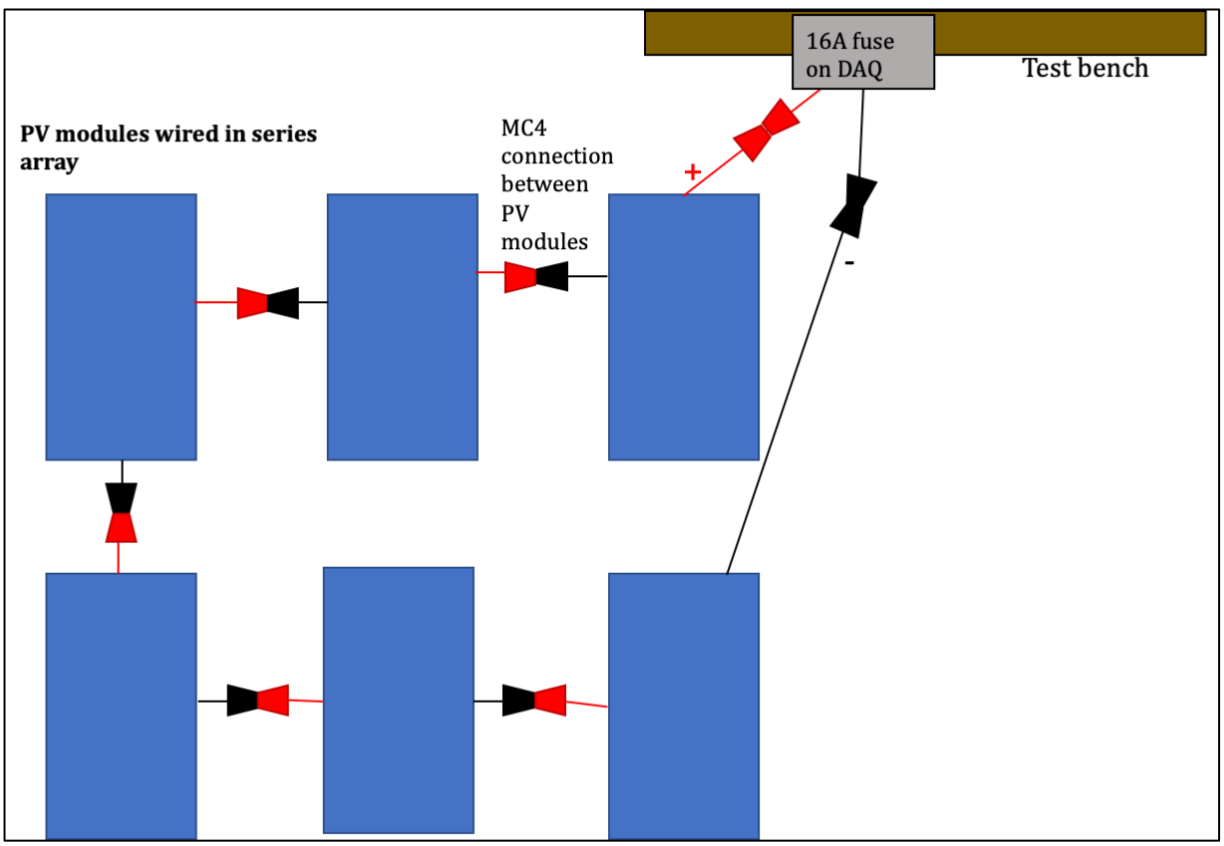


Figure 5. Diagram of PV modules in a series circuit.

Figure 6. Two MC4 connectors being connected.

  g. Go to step 6 for how to connect the PV array to the test bench.

9. If the PV array needs to incorporate **parallel** circuits, then follow these steps:
   h. Obtain the parallel adapter. This adapter will facilitate the connection of up to two "strands" of PV modules in series to be connected in parallel.

Figure 7. Parallel adapter for PV array circuits that have two parallel strands.

   i. Connect the PV modules in series in each "strand" first before connecting the strands in parallel.
   j. Then, to connect the two strands in parallel, connect the negative end of each strand to the two negative, open MC4 connectors on the parallel adapter, and connect the positive end of each strand to the two positive, open MC4 connectors on the adapter.

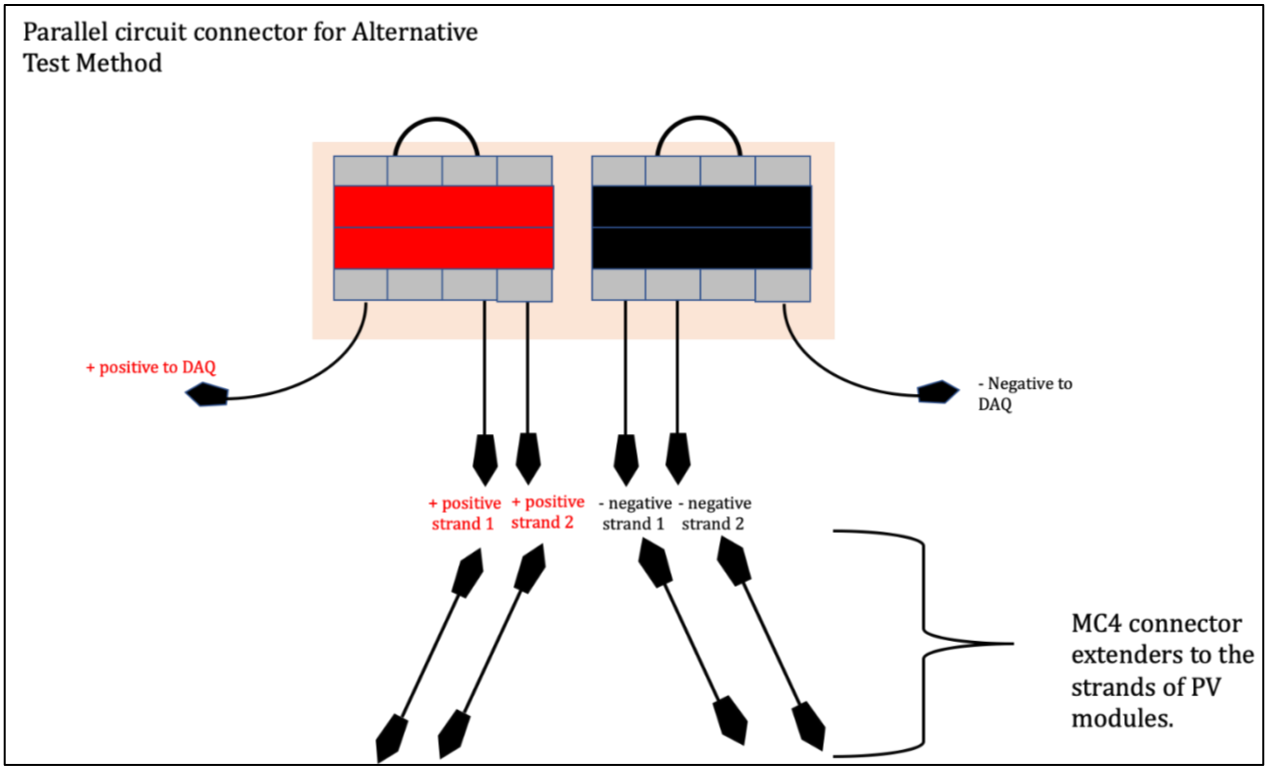


Figure 8. How to connect to the parallel adapter.

10. Once the PV array is configured, it should then be connected to the test bench. Before connecting the array, note that once the negative and positive ends of the PV array are both connected to the test bench, power will automatically be supplied. To have more control over the power input, there are several things that can be done:
    k. If the 16A fuse is included in the circuit, open/ disconnect it using its switch, which will open the circuit and not allow power input to the controller/ pump.
    l. If the SWP has an external controller, it may have an on/off switch; if so, switch it to the OFF position until ready to test.
    m. If there are no switches that be easily adjusted to control the power input, it is best practice to wait to plug in the negative MC4 connector from the PV array to the DAQ until the testers are ready to test.
11. Also, before connecting the PV array to the test bench, ensure that the very last electrical connection made is always a MC4 connection and not a bare wire/ screw terminal connection. **Handling bare, exposed wire to close the circuit is unsafe should never be practiced.**
12. To connect each type of array, follow these steps:
    n. For a series circuit:
        i. Connect the open positive MC4 connector on the first PV module in the series and the open negative MC4 connector on the last PV module in the series to the MC4-end of the MC4-to-wire adapter already connected to the input power terminal blocks on the test bench (this was done in step 3).
    o. For a parallel circuit:

i. Referring to the photo above depicting the parallel adapter, connect the MC4 connectors on either side to the MC4-end of the MC4-to-wire adapter connected to the input power screw terminal on the test bench.

13. Before testing, ensure the PV-end and pump-end are wired up correctly. For additional instructions on the general wiring for the test bench, refer to the *1 SWP Testing Set up* SOP.

Testing

14. The tests that will be performed using this method are the exact same tests as performed using the Chroma; refer to the testing SOPs specific to each test conducted to follow the specific steps. The only difference in the test procedures is related to how the input power is set for the system.
15. Normally, the Chroma is used to specify each irradiance step during testing; however, to control the input power when using a PV array, semi-clear material will be used to lower the input power from the 1000 W/m2 step (which should be available when no semi-clear material is used).
16. One tester will adjust the input power by placing semi-clear material on top of some of the PV modules to produce shade and reduce the current draw, which ultimately lowers the power input to the SWP. While one of the testers does this, the second tester will be reading the power input in LabView on the laptop and notify the other tester whether or not they need coverage or less (based upon the measured PV power in on the computer in LabView).

Figure 9. Semi-clear plastic squares to provide some coverage to PV modules to reduce and control power input.

Figure 10. One tester at the test bench laptop to record results; another tester in charge of the PV array shading.

17. For instance, to simulate all irradiance steps, the tester would add/ subtract semi-clear coverage on the various PV modules until the target irradiance step input power is observed on the computer, and the tester at the test bench can set the system pressure and record a data file at that input power and pressure before moving onto the next irradiance step.
18. Note that while covering PV modules, it makes sense to occasionally monitor the PV modules using an infrared camera, if possible, to ensure there aren't any significant "hot spots" due to coverage. Using semi-clear materials instead of solid/ non-clear materials is one way to help prevent hot spots in the PV modules, and also dispersing the coverage so that not only one PV module is being actively covered, but multiple are, is another way to prevent this occurrence.
    p. Hot spots in PV modules may have the ability to damage them or cause a safety hazard, so be cognizant of this possibility and try to reduce risk.

Appendix A- Tips on PV array wiring/ planning

When a SWP needs to be tested using this alternative method, the PV array must be planned and designed before testing should begin, as mentioned in this procedure above. It makes sense for a test lab to have several 250W and several 300W PV modules, and there are additional, smaller PV modules on-hand; however, there may not be enough variation in sizes and number of certain sizes to build a PV array to exactly match the ratings of the system in all cases. If this is the case, the tester shall discuss further with the Lab Manager to determine next steps.

Example

The Figure below shows an example PV array that was designed and then built to test one SWP that was incompatible with the Chroma. The maximum rated input parameters for this particular SWP was approximately 148V_{oc}, 16.4I_{sc}, and 2427W at TMOT.

Understanding basic rules of electrical circuits can help plan how to design one for testing. One helpful rule to remember is that when two series of circuits are in parallel, their voltage is the same; so, the voltage does not change when they are wired together in parallel; their current on the other hand will double. So, if you need higher current input for a pump, having two series circuits in parallel might make the most sense. Stringing circuits in series, however, is opposite, where voltage will increase with each PV module strung in series, but the current through a strand will remain the same. It is best practice to wire PV modules together that have the same power parameters; otherwise, the circuits will be limited by the smallest PV module.

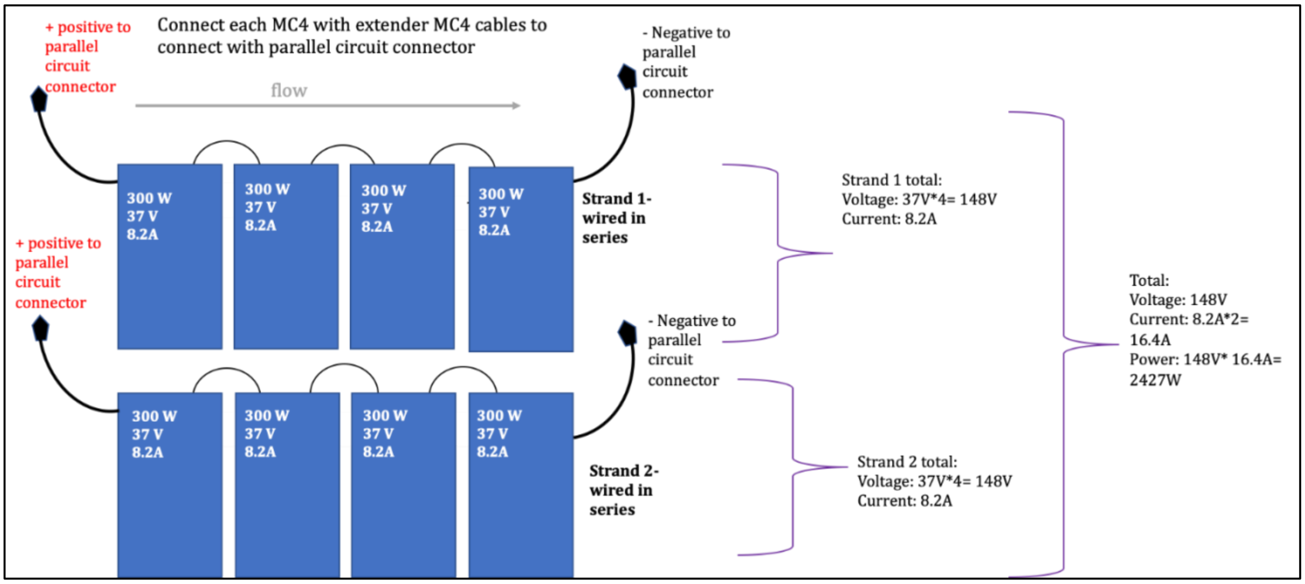


Figure 11. Example PV array design using series and parallel circuits.

Version	Date	Summary
1.0	8/31/22	Initial drafting of this SOP.

Scope / Field of Application

This procedure will encompass the process for creating a report that details the information gathered over the course of SWP testing. Parts of the reporting process will be covered and completed as a part of the specific test procedure so this will mainly focus on the layout of the reporting template, formatting, and creating a final report PDF.

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customized by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

SWP – Solar water pump

SOP – Standard operating procedure

Responsibilities

SWP tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks, if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test results, and provides input as needed. Also, may communicate directly with the client, as needed.

Pre-Test Preparation

Before completing this procedure, all required tests and procedures must be completed and all data needs to be analyzed. This procedure will walk through compiling the final data and results from the applicable tests.

Procedure

Reporting Template Overall

The report will be generated from the *SWP Reporting Template.*

This template should be copied from the “Testing_Templates” folder into the specific pump’s testing folder and renamed to the name of the specific. For more detail on setting up the proper file structure and templates, see *2 SWP Intake and Visual Screening SOP*.

Each of the individual test SOPs will include a “Reporting” section that details how to enter the specific tests information into the reporting template, so for information about specific sections within the report, navigate to that section’s relevant SOP.

The *SWP reporting template* consists of the following tabs:

Figure 1: Reporting spreadsheet tabs.

The pink tabs represent the tabs that will end up in the final report PDF. The blue tab has some general instructions and tips for filling out the spreadsheet. The green tabs are export tabs that are used to aggregate data.

1. Start with reviewing the *Instructions* tab on the far left. This tab gives a few general instructions such as:
    a. The *Title Page* and *Visual Screening* tabs are meant to be completed during the intake and visual screening process with the exception for the Internal Inspection section within the *Visual Screening*, which will be completed at the end of the performance testing (see *9 SWP Internal Inspection SOP*)
    b. Within the tabs, the pale-yellow cells need user input, and the blue cells contain a drop-down menu for the user to select from.
        i. If any yellow cells are left blank on purpose, fill in “--" to show that the value wasn’t relevant or available.
    c. DO NOT delete or insert any rows or cells, because this will affect the data export. Hide any unneeded rows.
    d. Each tab has instructions in the column to the right of the page that can be followed as you go.
2. In the *Title Page* tab – enter the information gathered during manufacture communication and during the intake and visual screening process. Also include a product photo that includes all the components laid out on a grid paper.
3. In the *Visual Screening* tab – follow the instructions in *2 SWP Intake and Visual Screening SOP* and *9 SWP Internal Inspection SOP* to properly fill out the sections in this tab.
4. In the *Test Results* tab – follow the testing SOPs, each of which will have instructions on how to fill out a specific section of the *Test Results* tab in the reporting template.
5. In the *Appendix A. Photos* tab – fill in relevant pictures and include small, descriptive captions in text boxes beneath each picture. Specifically, you should include:
    a. Photos of all components (all sides)
    b. Close-up photos of any labels on components
    c. Photos of all packaging and any labels on the packaging
    d. Photos of included user manuals or operation guides
        i. Be sure to take pictures close enough that the words are clearly readable in the report.
    e. Any notable damages or hazards that are not notes in other areas of the report (i.e., packaging damages, dents or scratches on pump or controller, etc.)
    f. Any screenshots of advertisements or specifications found online

Formatting

1. After completely filling in each of the four pink tabs, go through each tab and clear the background color from all the blue and yellow cells. See the example in Figure 2.

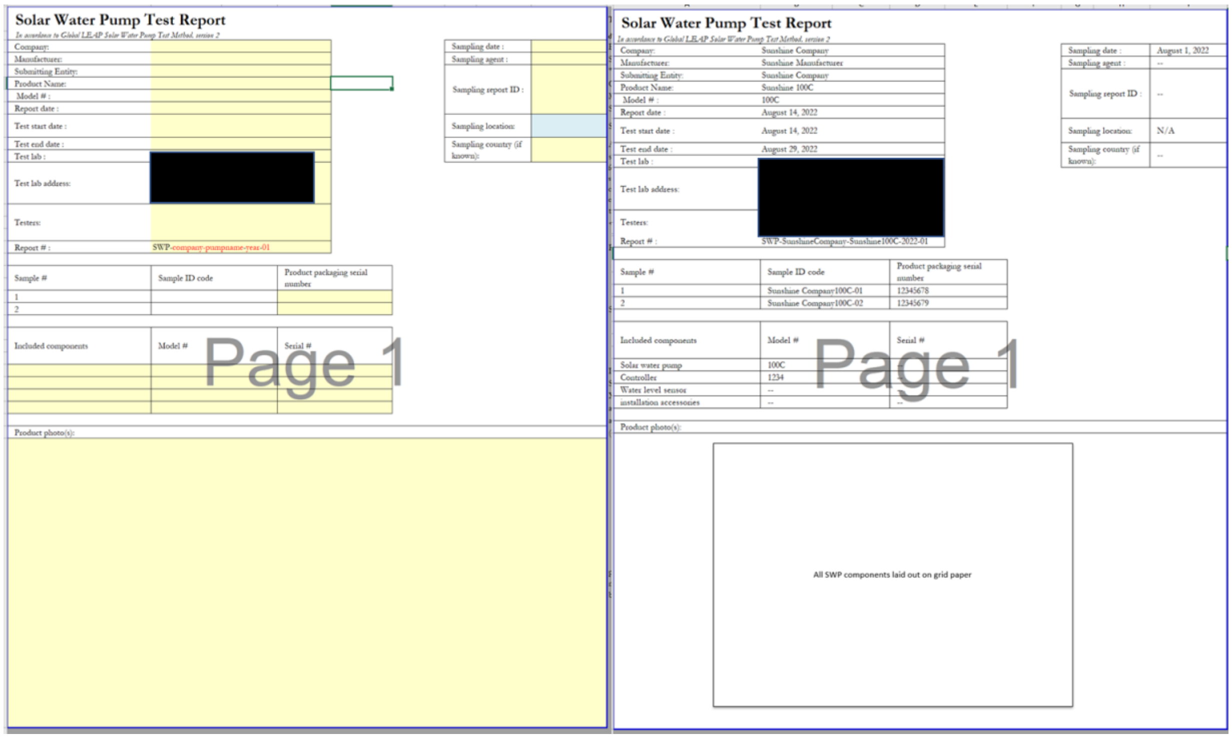


Figure 2: Title page from reporting template prior to being filled out (left) and an example title page finalized (right)

2. The reporting template is already in page break view (blue lines separating each page), but if not, navigate to the *View* tab in the Excel toolbar and select "Page Break View" as shown in Figure 3. Repeat this in each of pink tabs that is not already in "Page Break View".

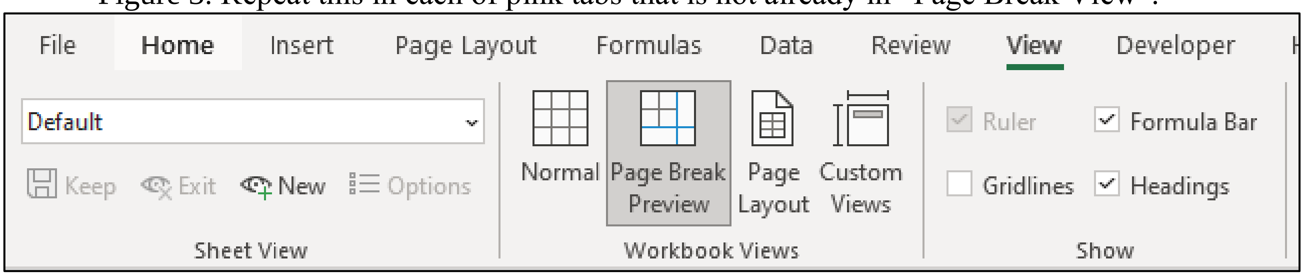
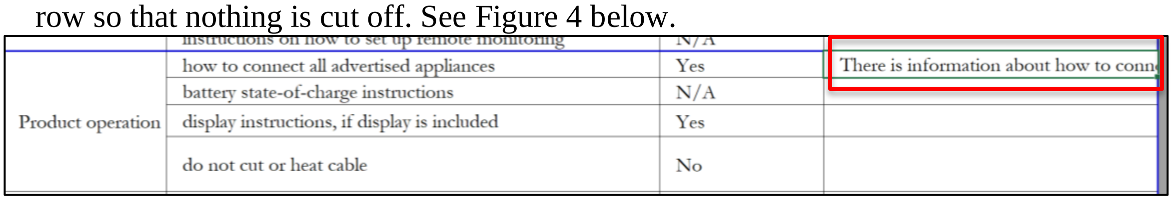


Figure 3: Page break view in excel.

3. In each of the pink tabs, go through and expand any rows that are cutting off text or comments. If there is a longer comment or header, wrap the text in the cell and expand the row so that nothing is cut off. See Figure 4 below.



Product operation	how to connect all advertised appliances	Yes	There is information about how to connect the water level sensors and a battery.
	battery state-of-charge instructions	N/A	
	display instructions, if display is included	Yes	
	do not cut or heat cable	No	

Figure 4: Cutoff text in a comment (top) and properly wrapped and expanded comment (bottom)

4. Adjust the page breaks (blue lines) so that each section is separated on a page (rather than half a section on one page and continuing another page), unless the break in sections is unavoidable. See Figure 5.

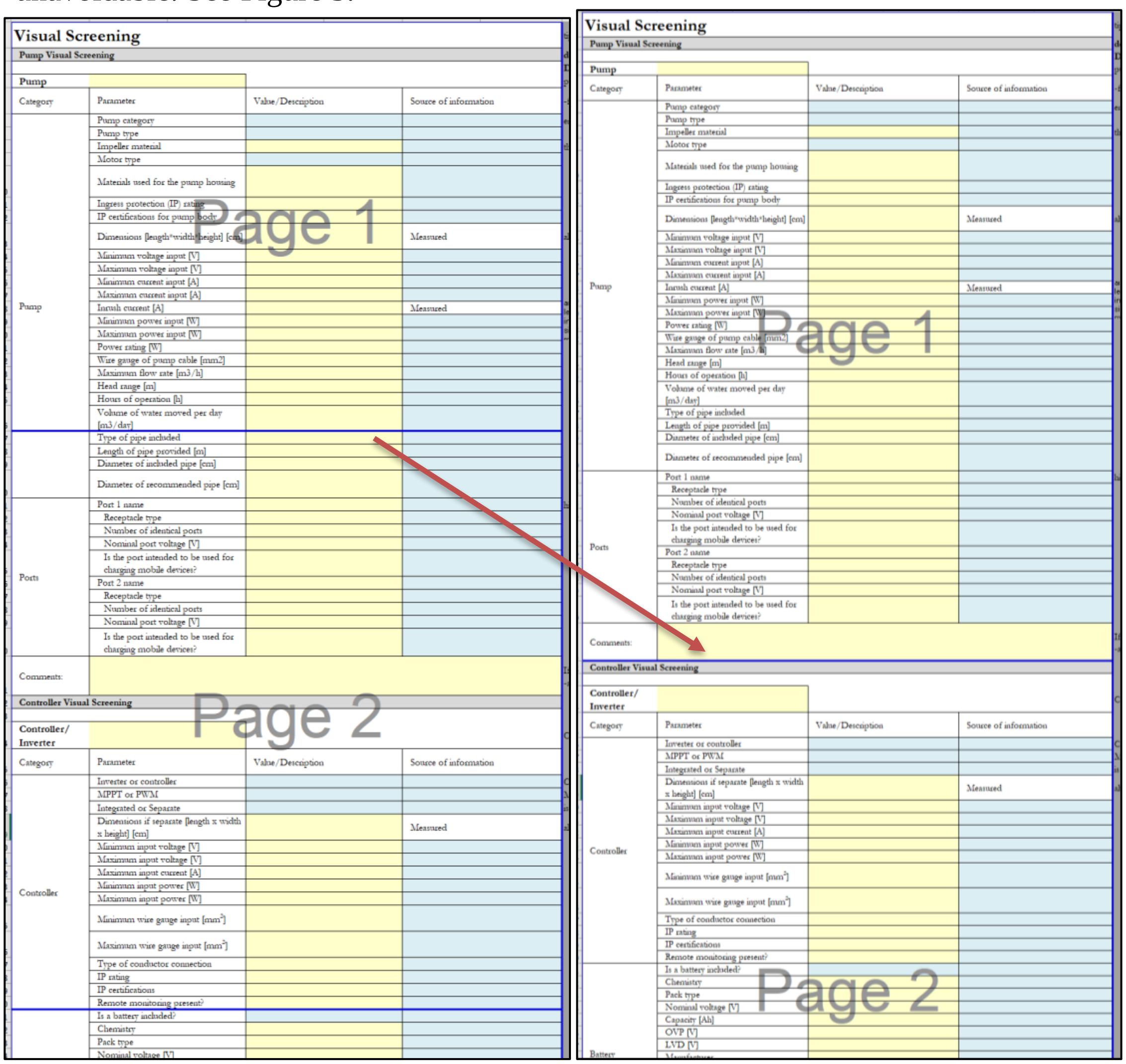


Figure 5: Moving page break to be between sections

5. For reported values (mainly in the *Test Results* tab) be sure to check column H for guides on how many significant figures to include. If a value has many digits displayed, be sure to reduce the number of significant figures to what is specified in column H. To do this, go to the “Number” section of the *Home* tab in the Excel toolbar, and select the button shown in Figure 6.

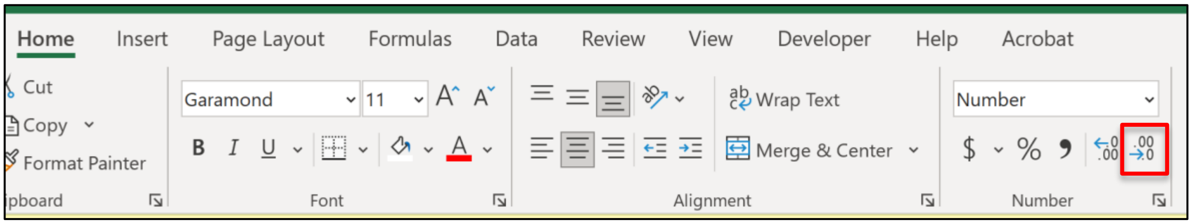


Figure 6: How to reduce the number of displayed digits in excel.

Useful operating range per typical solar day (Head Range Test)

Sample	Maximum wire to water efficiency [%]	Head at maximum efficiency [m]	Flow at maximum efficiency [lpm]	Maximum head [m]
1	37%	15.52054	24.30880	44.61563

2 sig figs for these values

Sample	Simulated irradiance at maximum head [W/m2]	Available PV power [W]	Measured PV power [W]	Simulated head [m]	Measured flow [lpm]	Wire to water efficiency [%]
1	700	398	393.0278732	0.0000000	92.2797659	0.0000000
	700	398	393.0278732	4.7979574	79.0859883	0.1195849
	700	398	392.8809572	10.9111062	63.7736193	0.2193778
	700	398	392.2904239	20.4871147	43.1615680	0.2791992
	700	398	391.8620830	30.2452345	26.3946827	0.2523388
	700	398	392.0323534	40.3497871	13.5400668	0.1726172
	700	398	392.6458841	50.0451052	5.5173604	0.0871035
	700	398	391.4098123	55.0874621	3.0138591	0.0525397
	700	398	391.1918996	58.8926380	1.8807132	0.0350701

PV power: 3 sig figs, simulated head, 3 sig figs

Useful operating range per typical solar day (Head Range Test)

Sample	Maximum wire to water efficiency [%]	Head at maximum efficiency [m]	Flow at maximum efficiency [lpm]	Maximum head [m]
1	37%	16	24	45

2 sig figs for these values

Sample	Simulated irradiance at maximum head [W/m2]	Available PV power [W]	Measured PV power [W]	Simulated head [m]	Measured flow [lpm]	Wire to water efficiency [%]
1	700	398	393	0.00	92.3	0.00%
	700	398	393	4.80	79.1	12.0%
	700	398	393	10.9	63.8	21.9%
	700	398	392	20.5	43.2	27.9%
	700	398	392	30.2	26.4	25.2%
	700	398	392	40.3	13.5	17.3%
	700	398	393	50.0	5.52	8.71%
	700	398	391	55.1	3.01	5.25%
	700	398	391	58.9	1.88	3.51%

PV power: 3 sig figs, simulated head, 3 sig figs

Figure 7: Properly formatting numbers in the "Test Results" tab of the reporting spreadsheet.

6. Before finalizing, go through the pink tabs and check for missing borders.
7. Check the *Export_publish* and *Export_all* tabs, and ensure there aren't any values out of place/ with the wrong reference. Specifically, look at the *Export_publish* tab more closely to ensure the correct number of sig figs are being reported (follow the instructions in column C) and that the correct references are being made (none of the values look incorrect). See the figure below.
    a. Note that these tabs have formulas that automatically pull specified values into the export tables, so generally no changes are needed- only if the wrong number of sig figs are being reported for any value or if the reference(s) need(s) to be updated.

	A	B	C
1	Metric	Value	Instructions: These items reference values in the pink input tabs. If anythin given metric and be sure to adjust the decimal places as needed, foloowing
2	Brand	0	
3	Product Type	0	
4	Model Number	0	
5	Power Supply Type	DC	
6	Manufacturer	0	
7	Warranty [months]	0	
8	Rated Controller Input Power [W]	0	
9	Rated Controller Input Voltage [V]	0	
10	Battery Integrated [yes/no]	no	
11	Pump Type	0	
12	Motor Type	0	
13	Pump Dimensions [L*W*H in cm]	0	
14	Rated Head Range [m]	0	
15	Rated Maximum Flow Rate [m3/h]	0	
16	Rated Pump Ingress Protection (IP) Rating	0	
17	Simulated PV Array Size [W]	0	make sure this is rounded to nearest whole number (no decimal
18	Simulated Head Value [m]	0	make sure this is rounded to nearest whole number (no decimal
19	Minimum Irradiance Required to Start Pump [per 50W/m2]	0	make sure this is rounded to nearest whole number (no decimal
20	Maximum Head [m]	0.0	make sure this is rounded to 1 decimal place
21	Maximum Wire-to-Water Efficiency [%] Simulated at 700W/m2	0%	make sure this is rounded to nearest whole number (no decimal
22	Head Value at Maximum Efficiency [m] Simulated at 700W/m2	0.0	make sure this is rounded to 1 decimal place
23	Flow Rate at Maximum Efficiency [L/min] Simulated at 700W/m2	0.0	make sure this is rounded to 1 decimal place
24	Low Irradiance Day: Hydraulic Energy per Day [Wh/day]	0.0	make sure this is rounded to 1 decimal place
25	Low Irradiance Day: Average Wire-to-Water Efficiency [%]	0%	make sure this is rounded to nearest whole number (no decimal
26	Low Irradiance Day: Total Volume of Water Moved per Solar Day [m3/day]	0.0	make sure this is rounded to 1 decimal place
27	Low Irradiance Day: Hours of Operation [h]	0.0	make sure this is rounded to 1 decimal place

Figure 8. *Export_publish* tab reporting. Follow the instrutions in column C.

8. The next step is to convert the Excel reporting document into a PDF. This can be done by holding down the "CTRL" key on Windows or "command" key on Mac while selecting all four pink tabs:

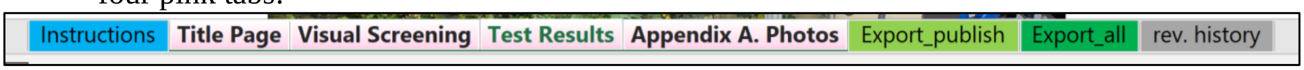


Figure 9: All four pink tabs selected.

9. Click on "File" then "Save as Adobe PDF".
10. The Acrobat PDFMaker box will pop up; verify that the space labeled "Sheets" in PDF has all the listed pink tabs that were selected.
11. Click on "Convert to PDF" (click "yes" if the popup window says the document must be saved).
12. Make sure to save the PDF in the pump's testing folder.
13. As soon as the PDF has been created, unlink the pink tabs in the Excel version of the report, by clicking on another tab (any other tab other than the linked pink tabs). If they remain linked on accident and any more changes are made, it may result in error throughout the entire workbook.
14. It is recommended to go through the PDF and look for formatting errors. Typically, missing borders, cut-off text, or improper page breaks can be seen more obviously in the PDF report. The errors identified in the PDF can be edited in parallel in the excel spreadsheet. If changes are needed, repeat steps 7-11 for recreating the report PDF.
15. After the PDF is formatted, send the updated draft to the Lab Manager for them to make the final review. There may be some back-and-forth if additional updates are needed.
16. Before finalizing the report, password protect the PDF so that nobody can edit it.
17. The Lab Manager will review and send the final report PDF and Excel versions to the client.

Troubleshooting

1. If there are blank pages in the PDF report, the likely cause is a page break that is located on a hidden row.

   a. To solve this, locate the place where the missing page is (for example, if blank page is right after the head range test results, navigate to the *Test Results* tab in the reporting spreadsheet and scroll to the head range section.
   b. Unhide any rows that are located right after the head range section. There will likely be a blue page break line within the hidden rows. Select the row directly beneath the page break line, right click, and select "Remove Page Break". Then re-hide the rows that were originally hidden.
2. If there is a missing border on cell that does not fill in when trying to correct it, try checking to see if there are hidden cells that the cell is merged with. Unhide any rows bordering the missing border, unmerge the cell with the missing border, and re-hide then re-merge the cell with only the unhidden cells.
3. If the spreadsheet is slow and glitching, check the size of file. If the size of the file is quite large, go through all of the tabs of the *Reporting* spreadsheet and compress the images to reduce the size of the images.
   a. This can be done clicking on the image, navigating to the *Picture Format* tab, selecting Compress Pictures, then selecting either "Print" or "Web", then press OK.
   b. Be sure to check once the report is printed to a PDF that all the images are still readable.

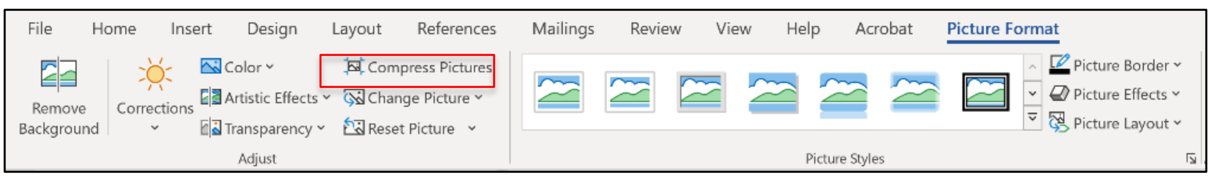


Figure 10: Picture format tab in Excel.

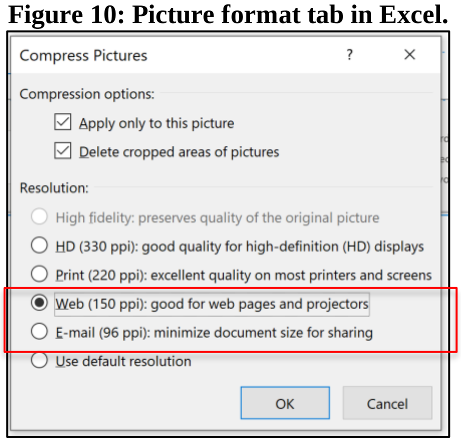


Figure 11: Compress Pictures menu in Excel.